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16. Abstract

An intercomparison of daily running mean air temperatures (RMT) for 14 Canadian weather stations and the movements of the lake freeze/thaw transition zone for 1961, 1963, and 1972 has confirmed a slightly modified version of McFadden's criterion. That is, the deep lakes of a region (> 6 meters mean depth) generally will freeze (thaw) when the 40-day RMT reaches 0°C (4°C) and the shallow lakes (< 6 meters mean depth) will freeze (thaw) when the 10-day RMT reaches 0°C (4°C). This finding has potential value for predicting the arrival and departure of the transition zone at a given locale.

ERTS 1 analysis results for the 1973 thaw season are presented. For the first time the complete evolution of the transition zone was observed, beginning in the U.S. upper Midwest and ending in the Canadian Arctic Islands. The orientation of the 1973 thaw transition zone (northwest–southeast) is identical to that observed for the 1972 freeze transition zone, suggesting that latent and sensible heat transfer are the dominant processes controlling both lake freezing and thawing.

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PREFACE

The primary objective of this investigation is to identify any correlations between the freeze/thaw cycles of lakes and regional weather variations. To meet this objective ERTS 1 imagery of central Canada and north-central United States are examined on a seasonal basis. The ice conditions of certain major study lakes are noted using standard photo interpretation techniques. The observations are recorded on magnetic tape, and base maps are used to draw the position of the lake freeze/thaw transition zone. Weather data, as available from the U.S. National Weather Service and the Atmospheric Environment Service of Canada, are compared with the transition zone migration pattern to determine any correlations.

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SECTION 1.0
INTRODUCTION

This report is a comprehensive summary of all work performed under contract number NAS 5-21761 during the period December 1973 through May 1974. The presentation will consist of four parts: (1) the scope of work covered; (2) the results of ERTS 1 imagery analysis for the 1973 thaw season and a preliminary comparison with the movement of weather systems; (3) the results of an intercomparison of the transition zone and running mean temperature; and (4) recommendations for future work.

SECTION 2.0
ACCOMPLISHMENTS

As recommended in the last semi-annual report [1] under this contract, tasks associated with this effort have concentrated on two general areas:

(1) Numerical correlations between the position of the transition zone and regional weather data,

(2) Extended analysis of ERTS 1 imagery to the 1973 thaw season.

Developments within each of these task areas is reported below.

2.1 RUNNING MEAN TEMPERATURE STUDY

As one means of examining the interrelationship of the lake transition zone and regional climate, a task was begun to determine running mean temperatures for selected Canadian weather stations. The running mean temperature (RMT) is simply the mean daily air temperature averaged over a span of time, usually measured in days. Expressed mathematically the RMT for a number of days, n, is:

$$RMT_n = \frac{1}{n} \sum_{i=1}^{n} T_i,$$

where T is the mean daily air temperature. In effect the RMT_n is an integrator of mean air temperature for the previous n days. Thus RMT_{30} can be regarded as the mean monthly temperature, and RMT_1 is just another expression for the daily mean temperature.

By advancing the RMT calculation in successive days, the variation of integrated mean temperature over a period of time, such as a season, can be studied. This was the approach adopted for this investigation. A software routine was developed to accept daily maximum and minimum air temperature data and compute the RMT for any number of days over any specified time period. This routine provided the computational results reported in a later section of this report.

Weather data for the RMT program were extracted from Canadian meteorological records [2] for 1961, 1963, 1972, and 1973, the years for which transition zone observations are available. A total of 18 stations were used, 11 in Manitoba and 7 in Western Ontario (Figure 1). These stations provide resonably adequate coverage of the extreme eastern portion of the test site. (Because of large data volume, the inclusion of stations over the entire test site has not been attempted.) The temporal coverage of the data on a station-by-station basis is shown in Table 1; the coverage was restricted to the seasonal periods containing transition zone observations. Note that a significant number of stations (7) lack continuous records over the 12-year span of interest. This becomes a problem when intercomparisons between years are attempted.

2.2 ERTS IMAGERY ANALYSIS FOR THE 1973 THAW SEASON

The bulk of the effort during the last reporting period was directed towards completing the analysis of ERTS imagery for the 1973 thaw season. Early results from this task were reported in the last semi-annual report [1], and preliminary indications suggested that abundant observational data were available. These expectations were substantially confirmed by the subsequent analysis, a fact that contributed to a delay in completion of the analysis.

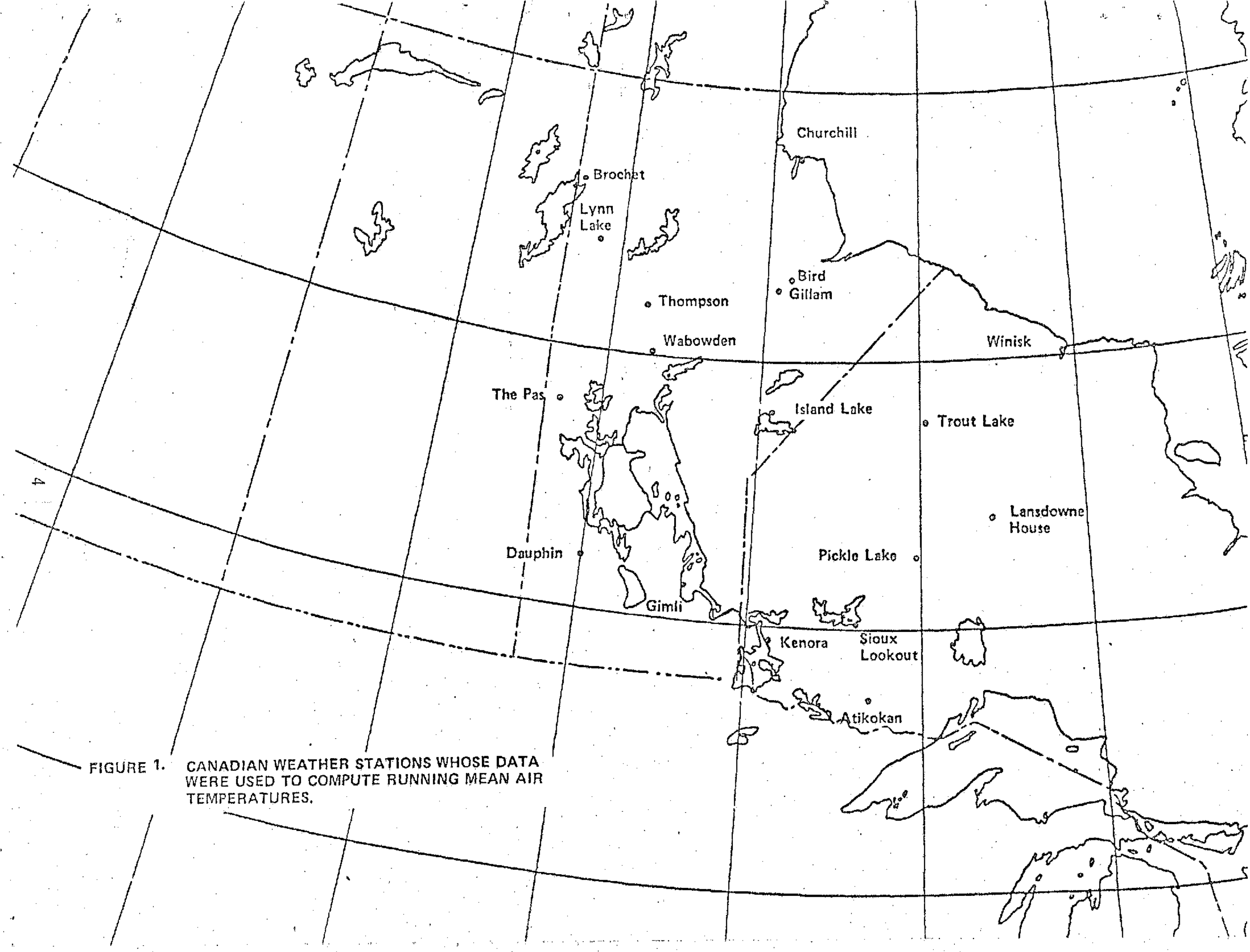


FIGURE 1. CANADIAN WEATHER STATIONS WHOSE DATA WERE USED TO COMPUTE RUNNING MEAN AIR TEMPERATURES.

Table 1. Temporal Coverage of Canadian Weather Station Air Temperature Data Used in RMT Calculations. (Note: Freeze Season = Sept, Oct, Nov; Thaw Season = Mar, Apr, May)

Province	Station	1961 Freeze Season	1963 Thaw Season	1963 Freeze Season	1972 Freeze Season	1973 Thaw Season
Manitoba	Bird	Yes	Yes	Yes	No	No
	Broche	Yes	Yes	Yes	Yes	Yes
	Churchill	Yes	Yes	Yes	Yes	Yes
	Dauphin	Yes	Yes	Yes	Yes	Yes
	Gillam	Yes	No	No	Yes	Yes
	Gimli	Yes	Yes	Yes	Yes	Yes
	Island Lake	No	No	No	Yes	Yes
	Lynn Lake	Yes	Yes	Yes	Yes	Yes
	The Pas A	Yes	Yes	Yes	Yes	Yes
	Thompson	No	No	No	Yes	Yes
	Wabowden	Yes	Yes	No	No	No
Ontario	Atikokan	Yes	Yes	Yes	Yes	Yes
	Kenora A	Yes	Yes	Yes	Yes	Yes
	Lansdowne House	Yes	Yes	Yes	Yes	Yes
	Pickle Lake	Yes	Yes	Yes	Yes*	Yes
	Sioux Lookout	Yes	Yes	Yes	Yes	Yes
	Trout Lake	Yes	Yes	Yes	Yes	Yes
	Winisk	Yes	Yes	Yes	Yes*	Yes

*Indicates at least one month of missing data.

2.2.1 Major Study Lake Observations

Major Study Lakes are defined as those lakes for which morphometric data and/or historical freeze-thaw information are available. Of a total of 411 candidate lakes, 268 were finally chosen as study lakes. (See Reference 3 for a description of the selection process and a complete list of the study lakes.) The provision was made to expand the number of study lakes as the need arose.

Observations of study lake ice state during the thaw season began for ERTS imagery dated 05 March 1973 and continued up through 30 June 1973. During this ERTS 1 coverage period over 1300 individual ice state observations were made and recorded on Lake Observation Data Sheets [3]. The total number of study lakes was not increased beyond the 345 used to monitor the 1972 freeze season.

During the 1972 freeze season, four problem areas were encountered which hampered the lake ice survey:

- cloud cover
- lake size
- reflectance
- satellite coverage

Each of these proved to cause less difficulty during the 1973 survey.

Cloud cover was much less extensive and pervasive during the 1973 thaw season. The only cloudy period of any consequence occurred between mid April and the first week in May. The lack of persistent cloud cover is corrobarated by weather data [2] that show March and May to be below normal in total precipitation throughout the test site; April and

June, on the other hand, were normal or slightly above normal in total precipitation. Although clouds occasionally hampered the observation of specific lakes, on the whole cloud cover had little effect upon determination of the transition zone.

Due to the resolution limits of ERTS imagery, there is a practical minimum lake size beyond which reliable estimation of surface characteristics by visual means becomes virtually impossible. This lower bound, has been estimated at about 2 square kilometers. Consequently, all lakes smaller than $2km^2$ are effectively eliminated from the lake ice survey. This does not mean to infer that such lakes are undetectable; water bodies only a few acres in size can be distinguished on ERTS imagery [4]. However, detectability of ice cover during the critical freezing or thawing period becomes extremely uncertain for such small lakes.

Natural surface reflectance can serve as both an aid and deterrent in observing ice conditions. A partially ice covered lake can be indistinguishable from a sediment-laden, ice-free lake. Unless the ice is strongly reflecting, as in the case with fresh snow cover, or the ice-water boundery is sharply defined and angular, the ice condition of the lake cannot be determined. Fortunately, during the thaw season decaying ice appears to reflect more strongly in all ERTS bands than freshly formed ice characteristic of the freeze season. This is probably due to the multiple reflecting surfaces of ice crystals in such ice as opposed to the relative transparency of new ice. On the whole, variable reflectance is less of an interpretation problem during the thaw season.

As shown in Appendix A, satellite coverage of the test site during the spring of 1973 was excellent. Overlapping satellite swaths in the northern latitudes enabled day-to-day observations of certain lakes to be made. The only area in which the coverage could be considered poor is that along the western perimeter of Hudson Bay, north of 60° latitude. This hole in the data did limit the analysis somewhat, but the major conclusions are not believed to be affected.

2.2.2 Transition Zone Observations

With the exception of cloud-covered images or those swaths flown at an inappropriate time, much of the ERTS imagery proved useful in determining the thaw transition zone. Swaths in which the transition zone was observed are noted in Appendix A.

The conditions for observing the thaw transition zone are the inverse of those for the freeze transition zone. During the thaw season, the smallest lakes accompanied by the faster flowing sections of most rivers, lose their ice cover early, whereas the largest lakes tend to retain their ice for longer periods of time. This is a consequence of more rapid solar heating of the water layer below the ice in small, relatively shallow lakes in comparison to heating of a similar layer in large, relatively deep lakes. In effect a greater volume of water must be heated in large lakes before they begin to thaw.

The northern transition zone boundary (NTZ) is marked by the trace of an irregular line of open or partially open lakes. Under thaw conditions these lakes are typically the smallest ones in the region. Progressing southward, the percentage of open lakes increases until a point is reached where all lakes are completely ice free. The line marking the last lakes possessing a discernable fraction of ice cover represents the southern transition zone boundary (STZ). In every case the STZ includes the largest and presumably deepest lakes in the area. Thus, in determining the location of the thaw transition zone, the NTZ is the more imprecise observation. This fact probably accounts for some of the day-to-day discontinuities in the trace of the thaw season NTZ [5,6].

As a result of experience gained from analyzing earlier ERTS imagery, a consistent procedure was adopted for handling the thaw season imagery. All critical ice observations (i.e., NTZ and STZ analyses) were made by an intercomparison of identical ERTS scenes taken in bands 5 and 7. The near infrared (band 7) was chosen because of its characteristic high absorption by water and its ability to penetrate thin, cirrus clouds. On the other hand, the red (band 5) is absorbed less well by water and is reflected even more strongly by snow and ice. The infrared was used as the general observation medium and as an indicator of open water; the red band was relied upon as an indicator of ice cover, especially remnant ice. In general, the infrared band was most useful for differentiating the NTZ, while the red band proved indispensable for locating the STZ.

The relatively poor reflectance of snow and ice in the infrared led to the enhancement of subtle differences and contrasts in snow and ice covered lake surfaces. As a result many early thaw features not readily apparent from the visible bands could easily be detected with ERTS band 7. These early thaw features included: loss of snow cover, open fractures, fracture swarms, shoreline open water, open water at inlets and outlets, and mottled ice surfaces. Varying gray levels of reflectance from the ice surface, in contrast to a fairly uniform surface brightness, were interpreted as indicative of variable ice thickness, a presumed accompanyment to thawing.

Taken collectively, these features enabled photo interpreters to discriminate between lakes that were solidly frozen over from those that had begun to show signs of thawing. Unexpectedly, a well-defined boundary could be drawn separating the two lake ice conditions; this line of separation has come to be called the ice decay boundary (IDB). In every case in which both were visible the IDB lay well to the north of the transition zone. Obviously, the IDB has no counterpart during the freeze season, since at that time lakes are either frozen over or they are not.

SECTION 3.0
RESULTS

3.1 RUNNING MEAN TEMPERATURE STUDY

As stated previously, the primary objective of this investigation is to identify any correlations between the freeze-thaw cycles of lakes and regional weather variations. In keeping with this objective, a fairly detailed analysis of the 1972 freeze season has been conducted [1], in which the temporal shift of the transition zone, as determined from ERTS imagery, was compared with various mesoscole meteorological parameters. This report presents the results of a more intensive study of one of those parameters, running mean temperature.

3.1.1 Running Mean Temperature - Freeze Season

McFadden [7] has been able to show that lakes whose mean depths exceed 6 meters freeze over very close to the intersection date of the 40-day running mean air temperature (RMT_{40}) and the freezing temperature of water (32°F). He further suggests that lakes with mean depths less than 6 meters freeze over at about the time the 3-day running mean temperature (RMT_3) reaches the freezing temperature. A sample of his results for The Pas weather station during the 1961 freeze season is shown in Figure 2. The agreement between the observed freeze dates for both shallow and deep lakes and the intersection dates of the RMT curves with the freezing temperature is quite good. On the whole, the sample is typical of the results obtained for all weather stations used in McFadden's study.

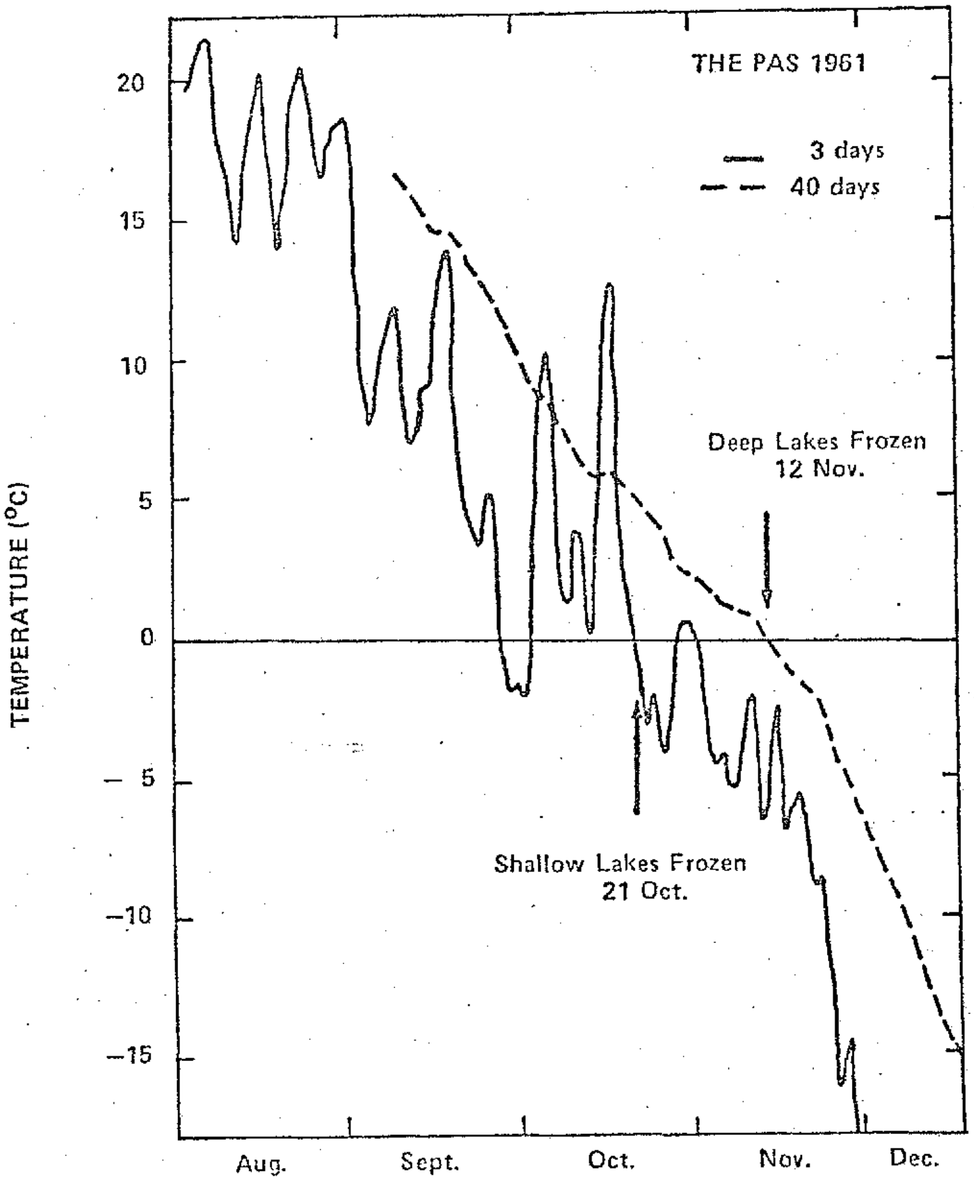


FIGURE 2. COMPARISON OF FREEZE DATES AND THE 3–DAY AND 40–DAY RUNNING MEAN AIR TEMPERATURES AT THE PAS, MANITOBA FOR 1961. (FROM McFADDEN [7])

The possibility of rendering McFadden's findings in map form rather than in graphical representation, was considered as a supplemental effort to this investigation. A map has the inherent quality of adding a 2-dimensional perspective to any observation which, in turn, can serve to enhance spatial features of the observation that otherwise would remain obscure. The approach adopted here was to plot the observed location of the transition zone on a map and compare that with computed RMT_n for weather stations in the vicinity. In order to retain a fairly high density of stations, the area of interest was confined to Manitoba and western Ontario (Figure 1), thus limiting the number of observations that could be compared in this manner.

By definition, the deep-lake freeze line and the northern transition zone boundary (NTZ) are identical, as are the shallow-lake freeze line and the southern transition zone boundary (STZ). Therefore, the deep-lake and shallow-lake freeze dates observed by McFadden are equivalent to the passage of the transition zone. This fact justifies a comparison of the transition zone and running mean temperature.

A comparison of McFadden's observed transition zone for the 1961 and 1963 freeze seasons [7] with the calculated RMT_{40} and RMT_{10} is presented in Figures 3-6. The 10-day running mean temperature was chosen because this base period produces fewer high frequency oscillations than the 3-day period used by McFadden (see Figure 2). If McFadden's criterion is correct, the NTZ and the RMT_{40} freezing temperature isotherm (32°F) should coincide, as should the STZ and the RMT_{10} freezing temperature isotherm.

A close examination of the 1961 freeze season (Figures 3-5) reveals that the criterion is indeed met, at least at the scale of the weather station spacing. In every instance,

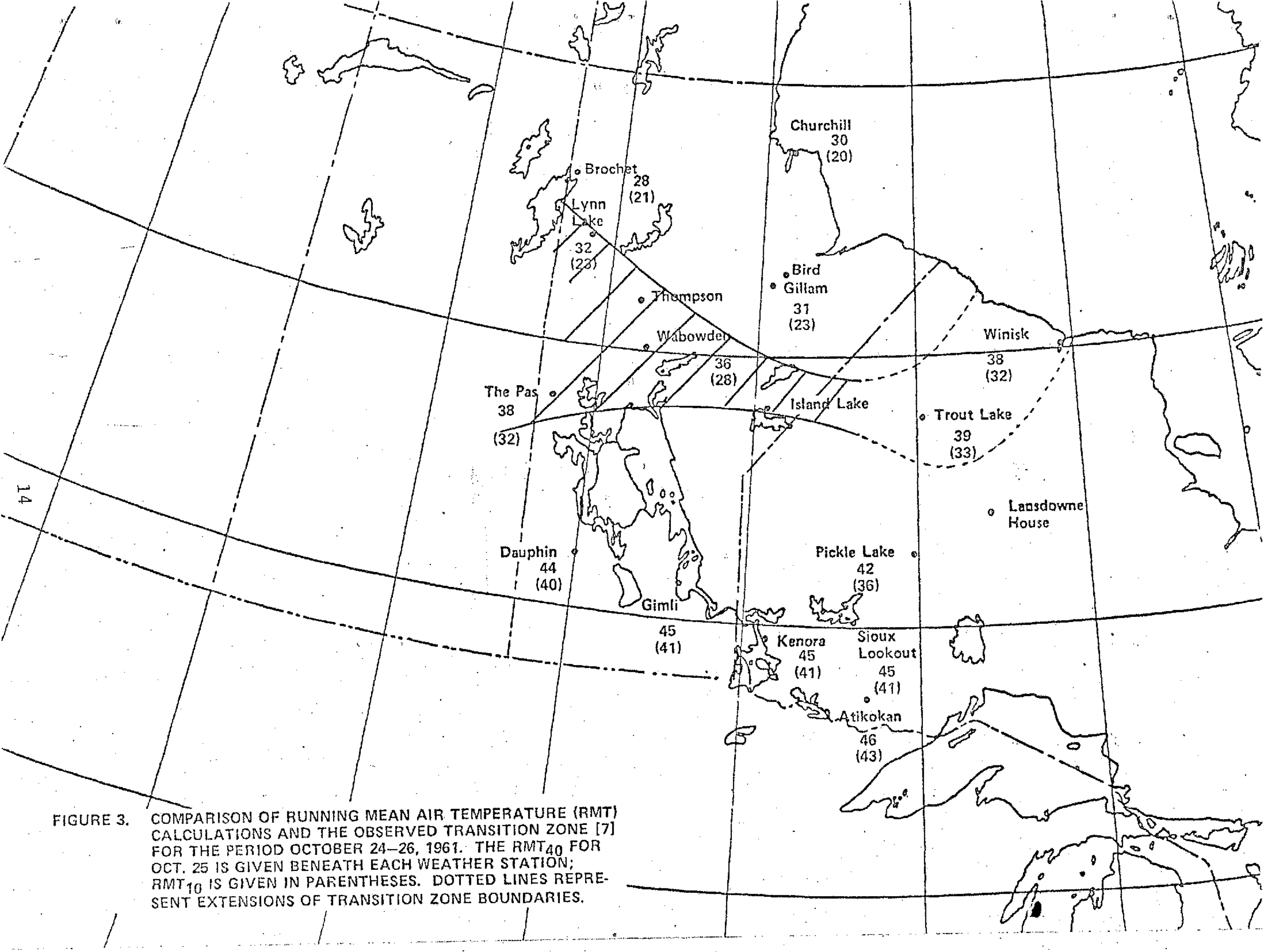


FIGURE 3. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [7] FOR THE PERIOD OCTOBER 24–26, 1961. THE RMT_{40} FOR OCT. 25 IS GIVEN BENEATH EACH WEATHER STATION; RMT_{10} IS GIVEN IN PARENTHESES. DOTTED LINES REPRESENT EXTENSIONS OF TRANSITION ZONE BOUNDARIES.

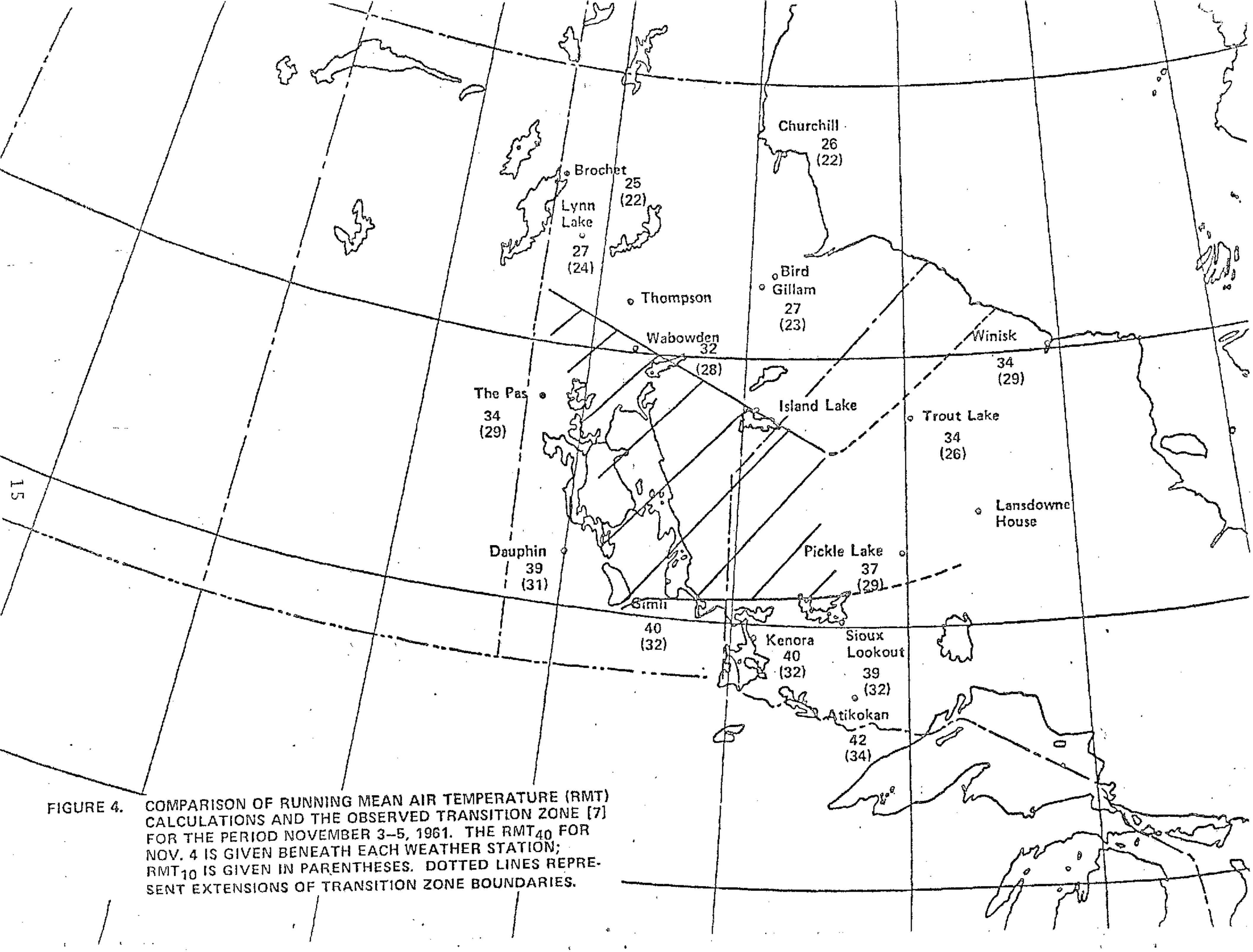


FIGURE 4. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [7] FOR THE PERIOD NOVEMBER 3–5, 1961. THE RMT_{40} FOR NOV. 4 IS GIVEN BENEATH EACH WEATHER STATION; RMT_{10} IS GIVEN IN PARENTHESES. DOTTED LINES REPRESENT EXTENSIONS OF TRANSITION ZONE BOUNDARIES.

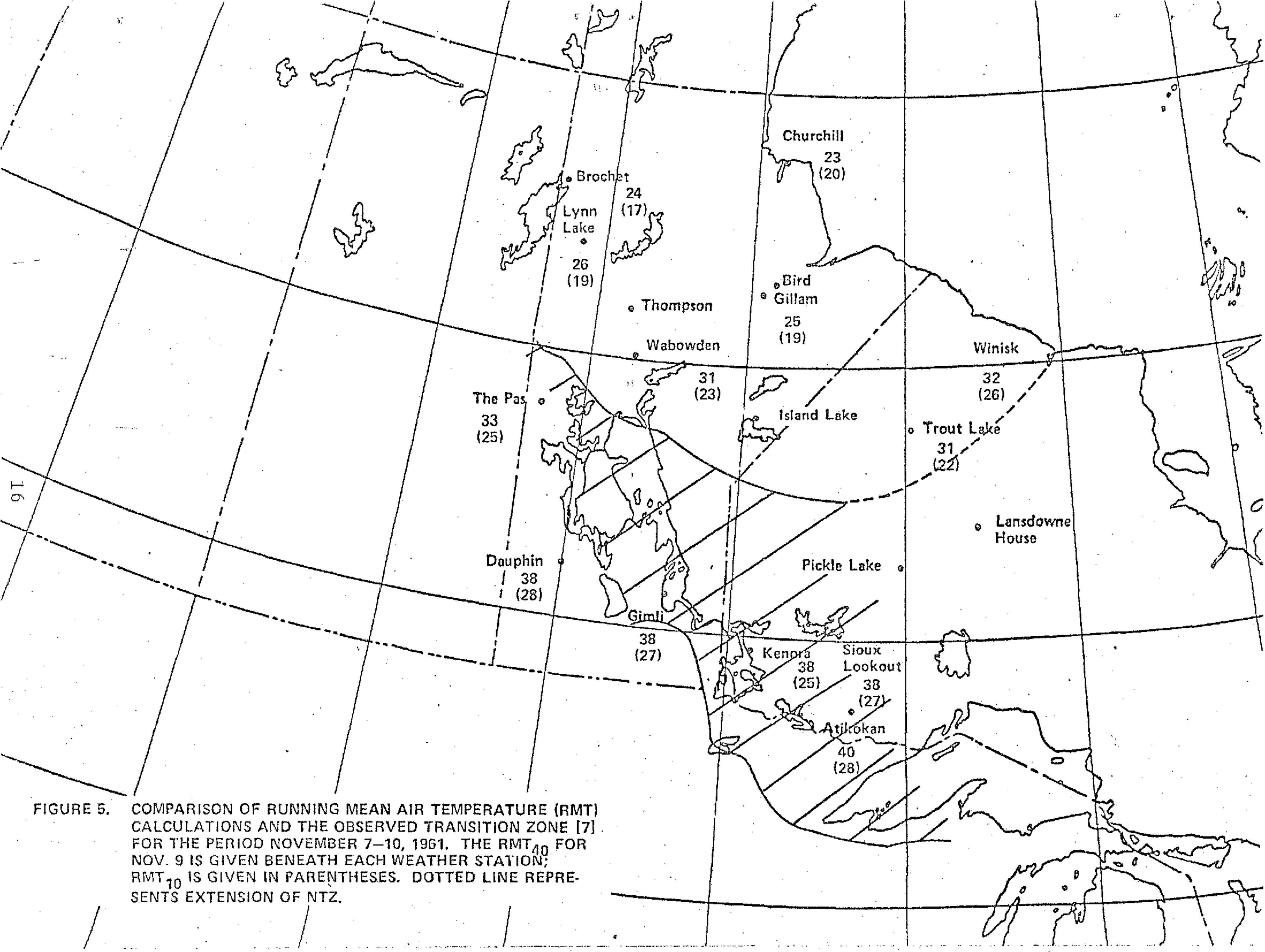


FIGURE 5. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [7] FOR THE PERIOD NOVEMBER 7–10, 1961. THE RMT_{40} FOR NOV. 9 IS GIVEN BENEATH EACH WEATHER STATION; RMT_{10} IS GIVEN IN PARENTHESES. DOTTED LINE REPRESENTS EXTENSION OF NTZ.

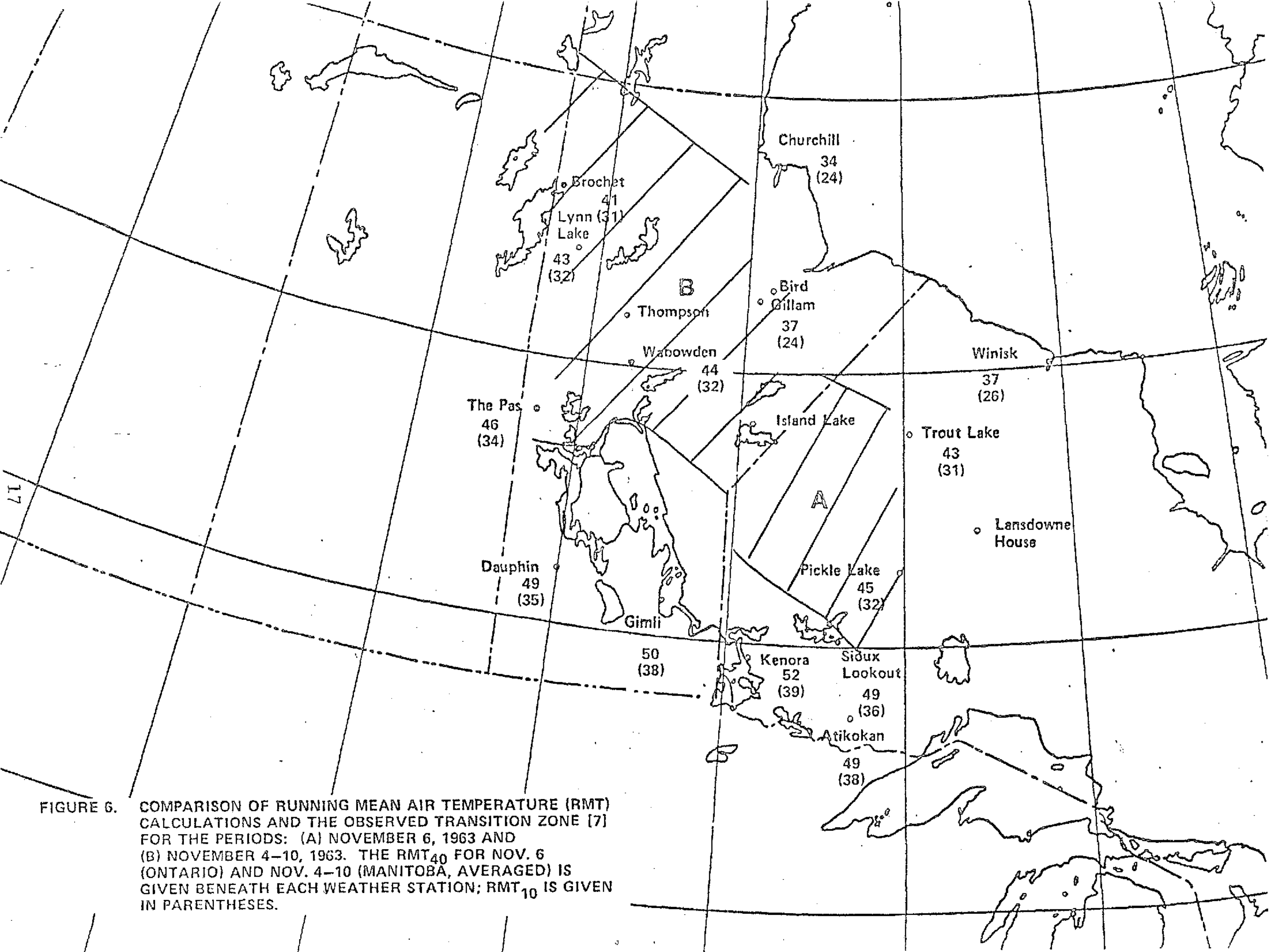


FIGURE 6. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [7] FOR THE PERIODS: (A) NOVEMBER 6, 1963 AND (B) NOVEMBER 4–10, 1963. THE RMT_{40} FOR NOV. 6 (ONTARIO) AND NOV. 4–10 (MANITOBA, AVERAGED) IS GIVEN BENEATH EACH WEATHER STATION; RMT_{10} IS GIVEN IN PARENTHESES.

all stations to the north of the NTZ have a RMT_{40} less than 32°F, whereas all stations south of the NTZ exceed 32°F. Similarly, all stations north of the STZ have a RMT_{10} less than 32°F, and all stations south of the STZ exceed 32°F. Those stations close to either transition zone boundary (e.g., Lynn Lake and The Pas in Figure 3) have running mean temperatures at exactly the freezing temperature. The fit is so good, that one is tempted to extend the transition zone solely on the basis of RMT calculations (Figures 3-5). It should be noted, however, that McFadden's criterion resulted from his observations of the transition zone; in large part this accounts for the goodness of fit.

Despite the simplicity and accuracy of the RMT method for locating the transition zone in space and time, the computational base period appears to vary from year to year. For example, in 1963 (Figure 6) the RMT_{40} and RMT_{10} define the NTZ and STZ much less well than they did in 1961; a transition zone drawn solely on the basis of RMT_{40} and RMT_{10} would differ considerably from the observed transition zone for the same period. As has been noted previously [8], the 1961 and 1963 freeze seasons differed appreciably in temperature.

The annual variation in the RMT base period is again obvious for the results from 1972 (Figures 7 and 8). As in the case of 1963, these latest results provide a less than optimum fit to McFadden's criterion; the transition zone for mid-November 1972 (Figure 8) is most incongruous of all.

Only a moderate effort is required to adjust the RMT base period (n) and produce results that better fit each observed transition zone. Such "tuning" of McFadden's criterion would only have value if (1) the adjusted RMT base period is applicable over the entire freeze season and/or (2) a relationship can be discovered between the base period and the

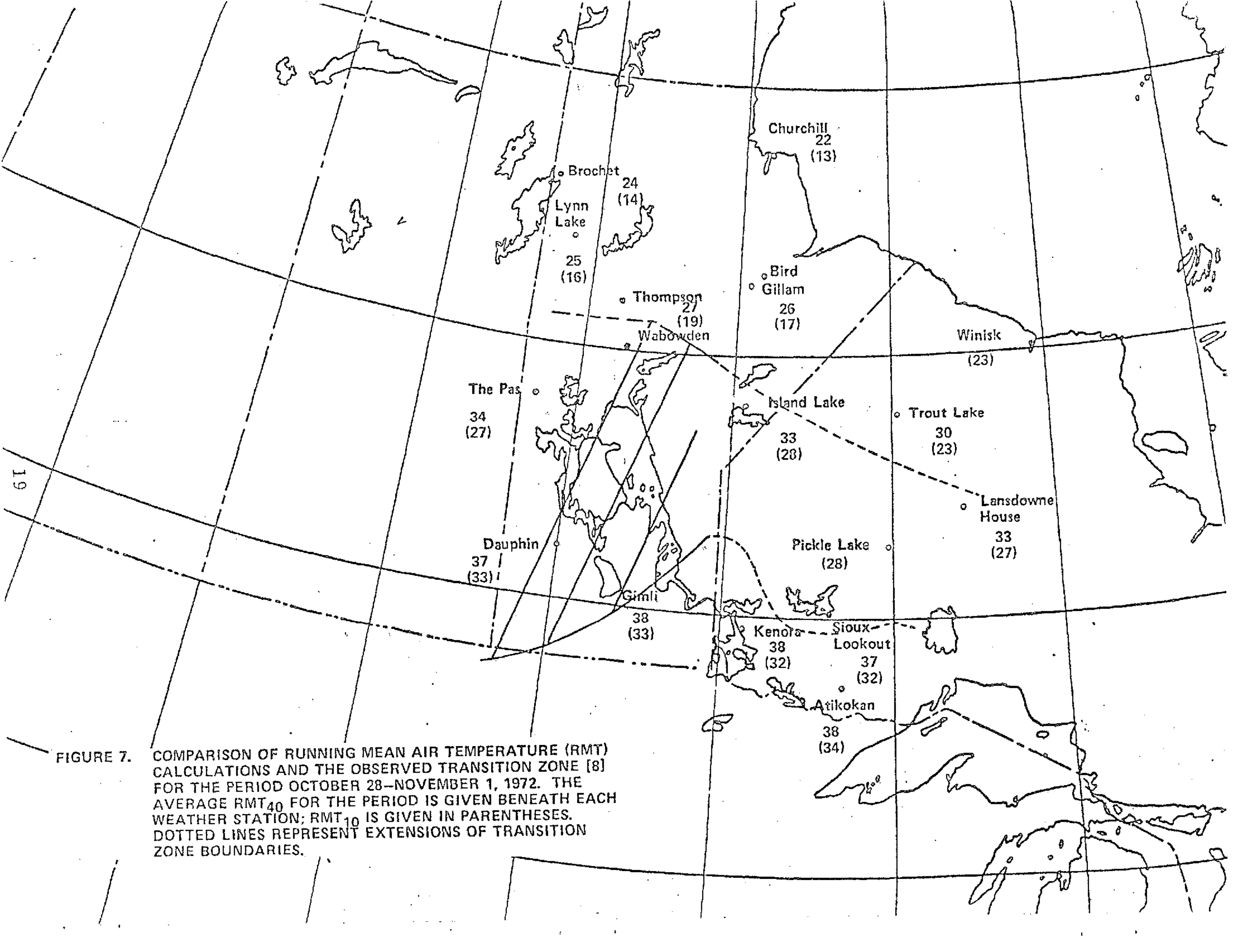


FIGURE 7. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [8] FOR THE PERIOD OCTOBER 28–NOVEMBER 1, 1972. THE AVERAGE RMT_{40} FOR THE PERIOD IS GIVEN BENEATH EACH WEATHER STATION; RMT_{10} IS GIVEN IN PARENTHESES. DOTTED LINES REPRESENT EXTENSIONS OF TRANSITION ZONE BOUNDARIES.

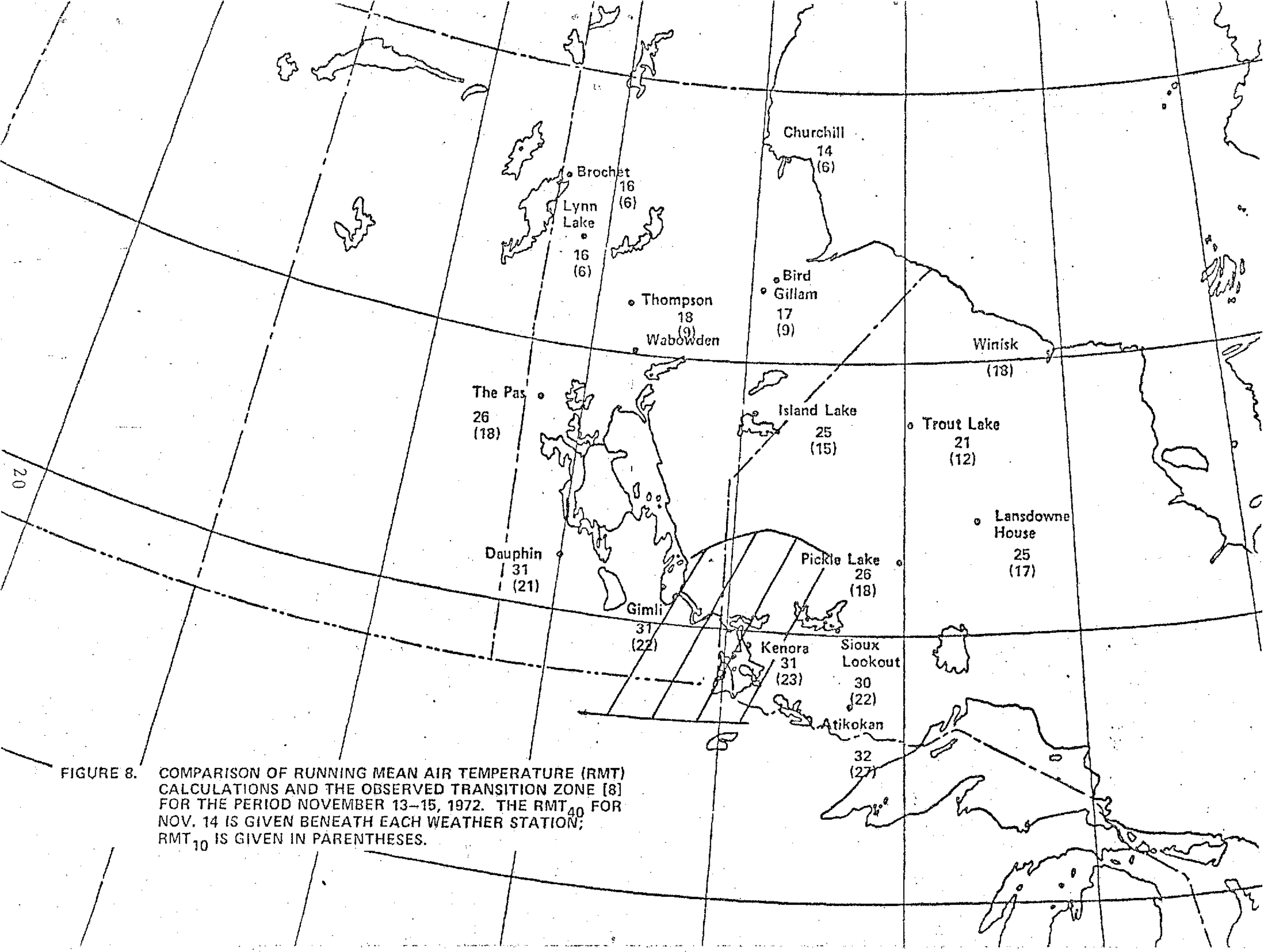


FIGURE 8. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [8] FOR THE PERIOD NOVEMBER 13–15, 1972. THE RMT_{40} FOR NOV. 14 IS GIVEN BENEATH EACH WEATHER STATION; RMT_{10} IS GIVEN IN PARENTHESES.

general climatology of each freeze season. That is, the transition zone could be accurately predicted in space and time, if the appropriate RMT base period was known a priori.

An extensive analysis of "tuned" base periods as seasonally or annually varying functions of regional climatology has not been attempted in this investigation. Future efforts along this line of research are recommended. In the meantime, McFadden's criterion is an acceptable means of placing the freeze transition zone.

3.1.2 Running Mean Temperature - Thaw Season

The corollary of McFadden's criterion for the thaw season states that deep lakes freeze over very close to the intersection date of the 40-day RMT and the temperature of maximum water density (4°C/39°F), whereas shallow lakes freeze over at about the time the 3-day running mean temperature reaches the temperature of maximum water density [7]. In fact, McFadden uses 5°C as the deicing temperature, but gives no reason for this selection. The reason the freezing temperature (0°C/32°F) is not used has to do with the physics of lake ice melting which largely occurs at the ice-water interface. Since the process is well understood, it is not discussed here.

Thaw season transition zone observations for which weather station data are available are sparse. At present only one observation, May 22, 1963, lies within the area of interest. The RMT results for this date are shown in Figure 9. In addition to the observed transition zone, dashed lines have been drawn to indicate transition zone boundaries based solely upon RMT data. With the sole exception of Lynn Lake, the agreement is excellent. Note that for the thaw season, if McFadden's criterion holds, the NTZ should coincide with the RMT_{10} 39°F isotherm and the STZ

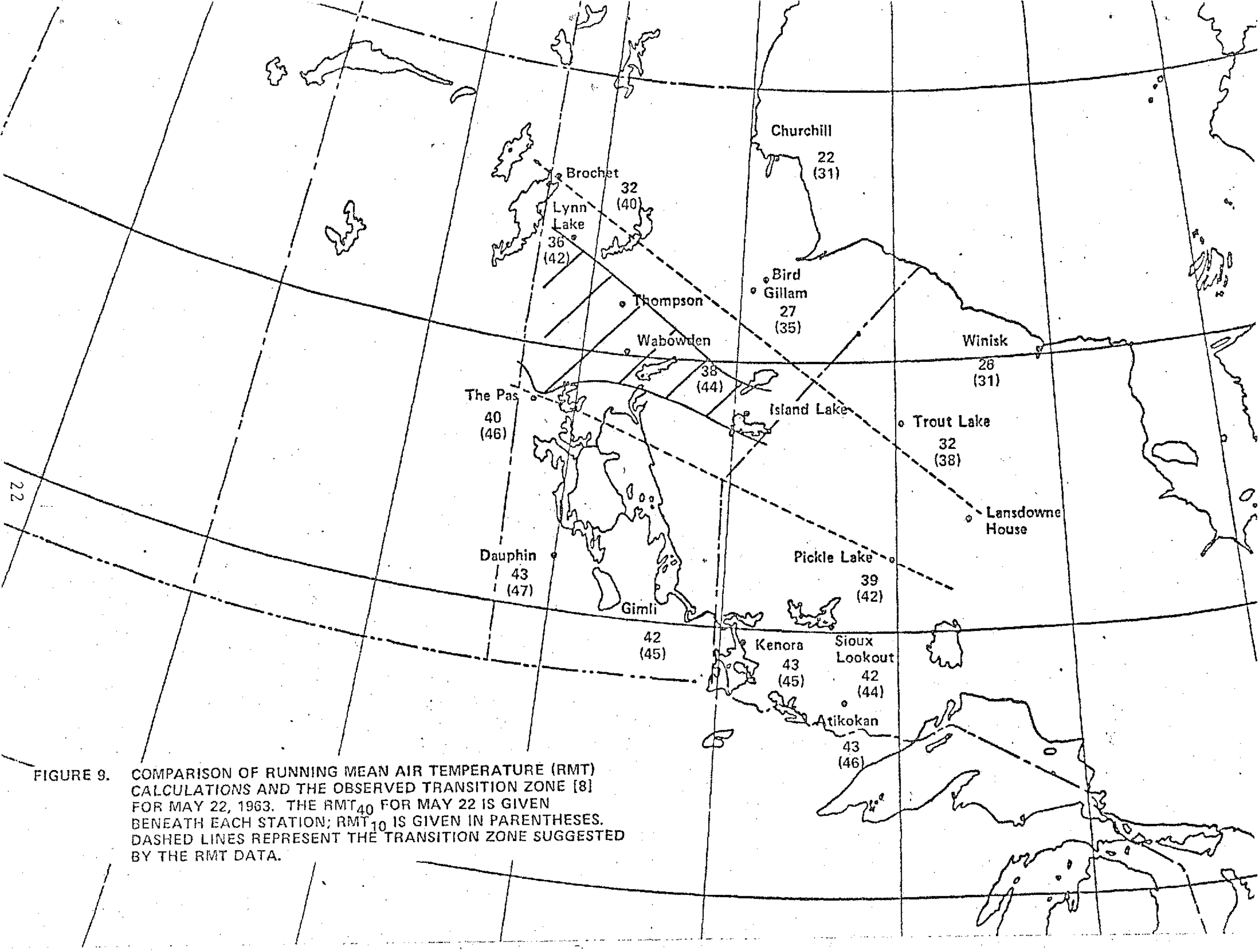


FIGURE 9. COMPARISON OF RUNNING MEAN AIR TEMPERATURE (RMT) CALCULATIONS AND THE OBSERVED TRANSITION ZONE [8] FOR MAY 22, 1963. THE RMT_{40} FOR MAY 22 IS GIVEN BENEATH EACH STATION; RMT_{10} IS GIVEN IN PARENTHESES. DASHED LINES REPRESENT THE TRANSITION ZONE SUGGESTED BY THE RMT DATA.

should coincide with the RMT_{40} 39°F isotherm. This corresponds to the shallow-lake thaw line and deep-lake thaw line respectively.

More thaw season data will become available as the 1973 observations reported in the next section are analyzed in detail. Be that as it may, the RMT method appears to be a credible means of deducing the transition zone for the thaw season as well as the freeze season.

3.2 THAW SEASON (1973)

As indicated previously, the 1973 thaw season provided an exceptional amount of analyzable ERTS imagery in comparison to the preceding freeze season. Consequently, migration of the transition zone was observable for more than 3 months in time and from the continental U.S. to the Beaufort Sea on space; ERTS provided the unique opportunity to examine for the first time, the complete evolution of the zone. Some of the early results of that examination are reported here.

3.2.1 Transition Zone Migration

The observations on which the results are based have been reported earlier [5,6] and need not be duplicated in this report. Suffice to say that, whereas several day-to-day observations appeared contradictory, for the most part, the analysis tended to show a transition zone of relatively uniform width trending consistently in a northwest-southeast direction. Those instances in which apparent conflicts arose are attributable to (a) real, abrupt shifts in the location of boundaries, (b) observational difficulties in precisely locating and orienting boundaries, and (c) interpretive differences between observers. A reexamination of the ERTS imagery, currently in progress, should resolve most inconsistencies, however, the basic positions of the transition zone as reported here are believed to be unaffected.

The thaw season transition zone was taken as the smoothed average of the base observations [5,6]; that is, an average trend of the daily variations in the locations of the NTZ and STZ was assumed to represent the trend of the zone over a period of time. In such manner, consecutive day inconsistencies were largely eliminated. An identical technique was applied to the ice decay boundary (IDB).

Averaged transition zone boundaries and ice decay boundaries for the 1973 thaw season are displayed in Figures 10 through 15. Interpolated boundaries are marked by dashes, and dates mark the approximate time and location of a given boundary observation. Typically, the outlined transition zone and IDB increase in age from east to west, but this is not always the case (e.g., Figure 12). By quickly scanning the figures from page to page, a sense of the motion of the zone can be obtained.

Two or more observations on the same day, separated by about 1500 miles give an instantaneous view of the transition zone on a continental scale. This view is readily apparent in Figures 13-15. These figures confirm the pronounced northwest-southeast trend of the transition zone independent of any temporal variations. Thus the thaw transition zone displays a remarkable similarity in orientation to the freeze transition zone [7,8]. Apparently, solar radiation plays less of a role in melting ice than had been thought, and running mean air temperature (i.e., sensible and latent heat transfer) is the controlling factor.

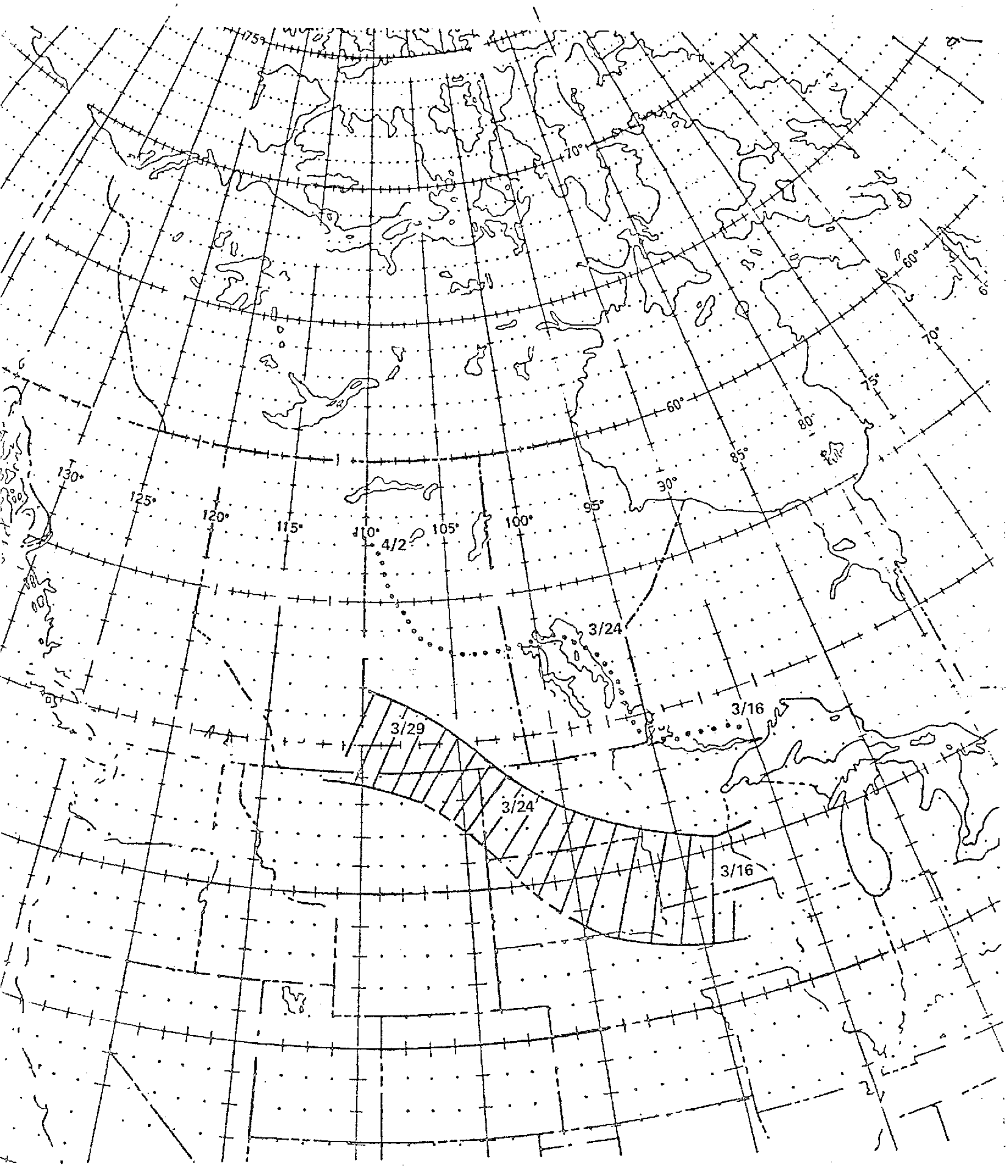


FIGURE 10. LAKE THAW TRANSITION ZONE AND ICE DECAY BOUNDARY (DOTTED) FOR THE PERIOD MARCH 16 THROUGH APRIL 2, 1973. DATES ON MAP INDICATE APPROXIMATE POSITIONS OF BOUNDARIES AT THOSE TIMES.

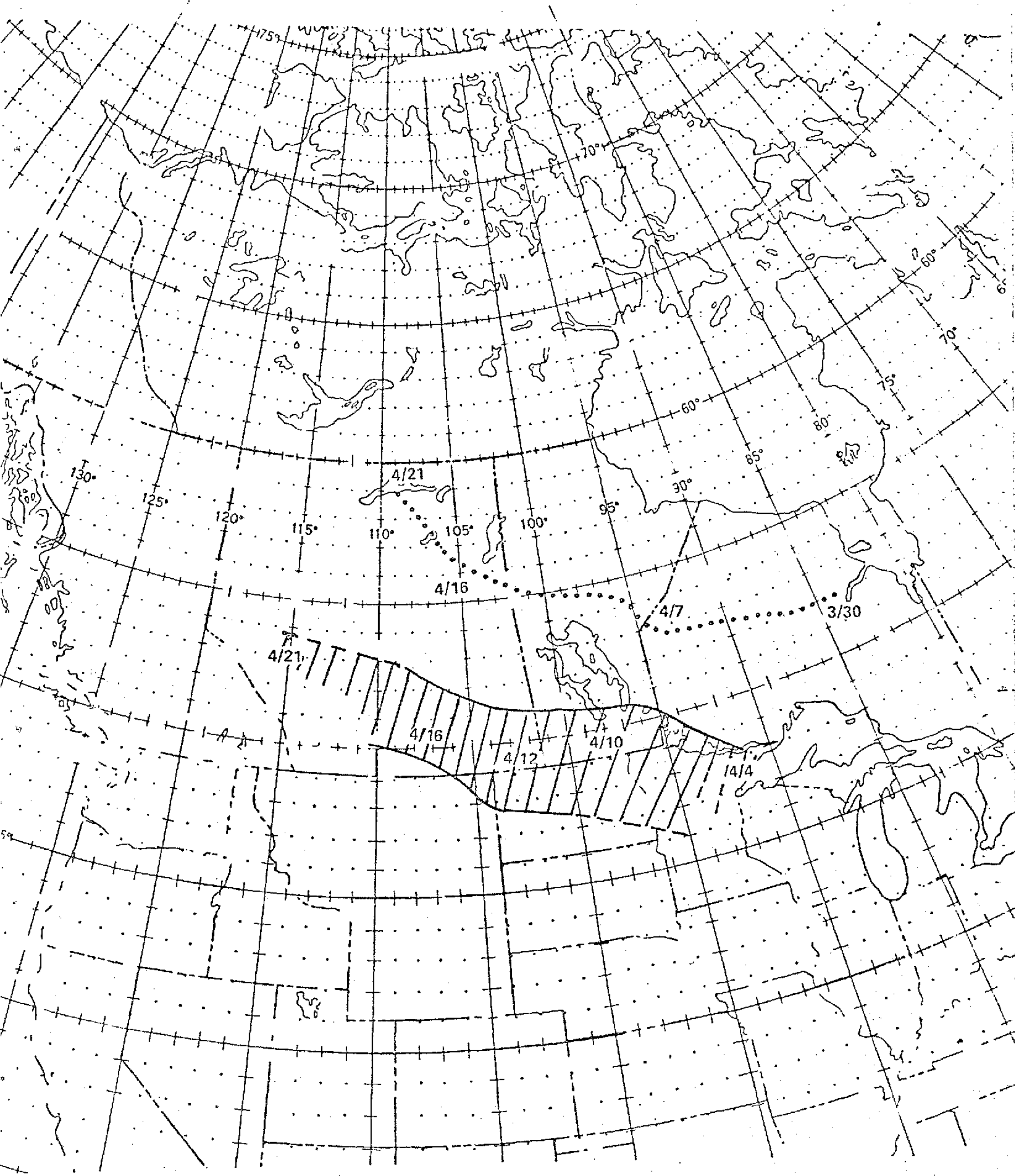


FIGURE 11. LAKE THAW TRANSITION ZONE AND ICE DECAY BOUNDARY (DOTTED) FOR THE PERIOD APRIL 4 THROUGH APRIL 21, 1973. DATES ON MAP INDICATE APPROXIMATE POSITION OF BOUNDARIES AT THOSE TIMES.

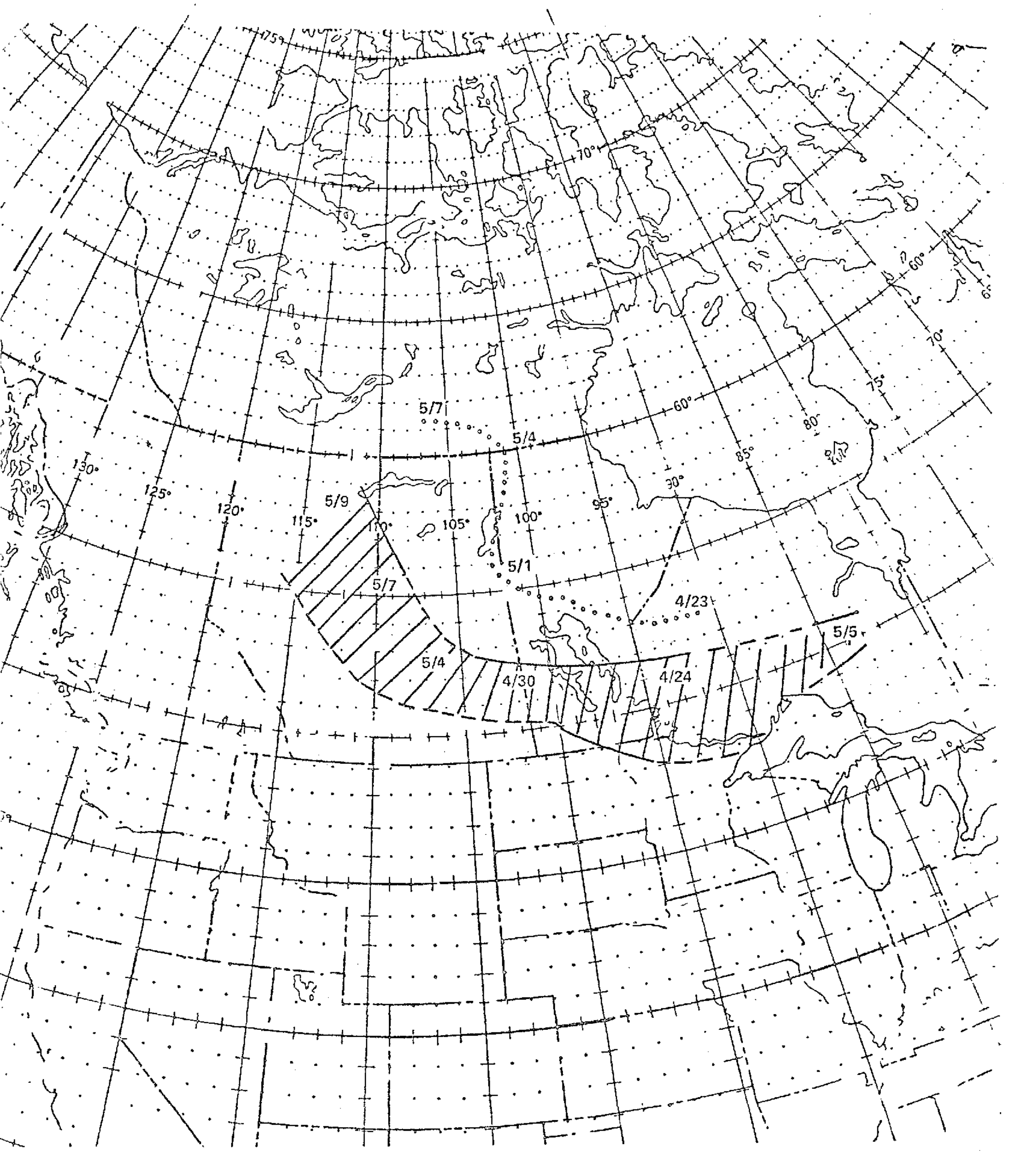


FIGURE 12. LAKE THAW TRANSITION ZONE AND ICE DECAY BOUNDARY (DOTTED) FOR THE PERIOD APRIL 23 THROUGH MAY 9, 1973. DATES ON MAPS INDICATE APPROXIMATE POSITION OF BOUNDARIES AT THOSE TIMES.

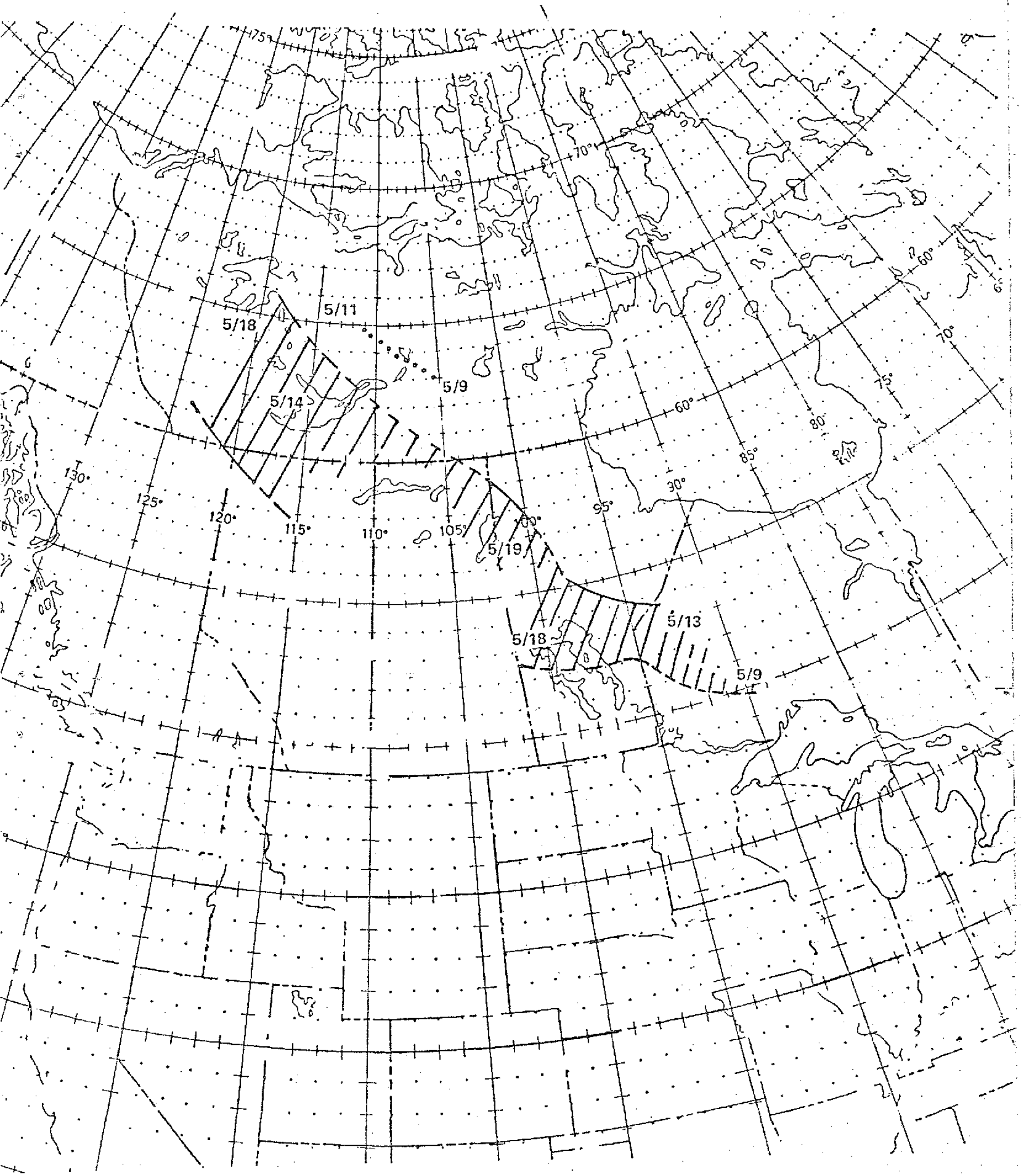


FIGURE 13. LAKE THAW TRANSITION ZONE AND ICE DECAY BOUNDARY (DOTTED) FOR THE PERIOD MAY 9 THROUGH MAY 18, 1973. DATES ON MAP INDICATE APPROXIMATE POSITION OF BOUNDARIES AT THOSE TIMES.

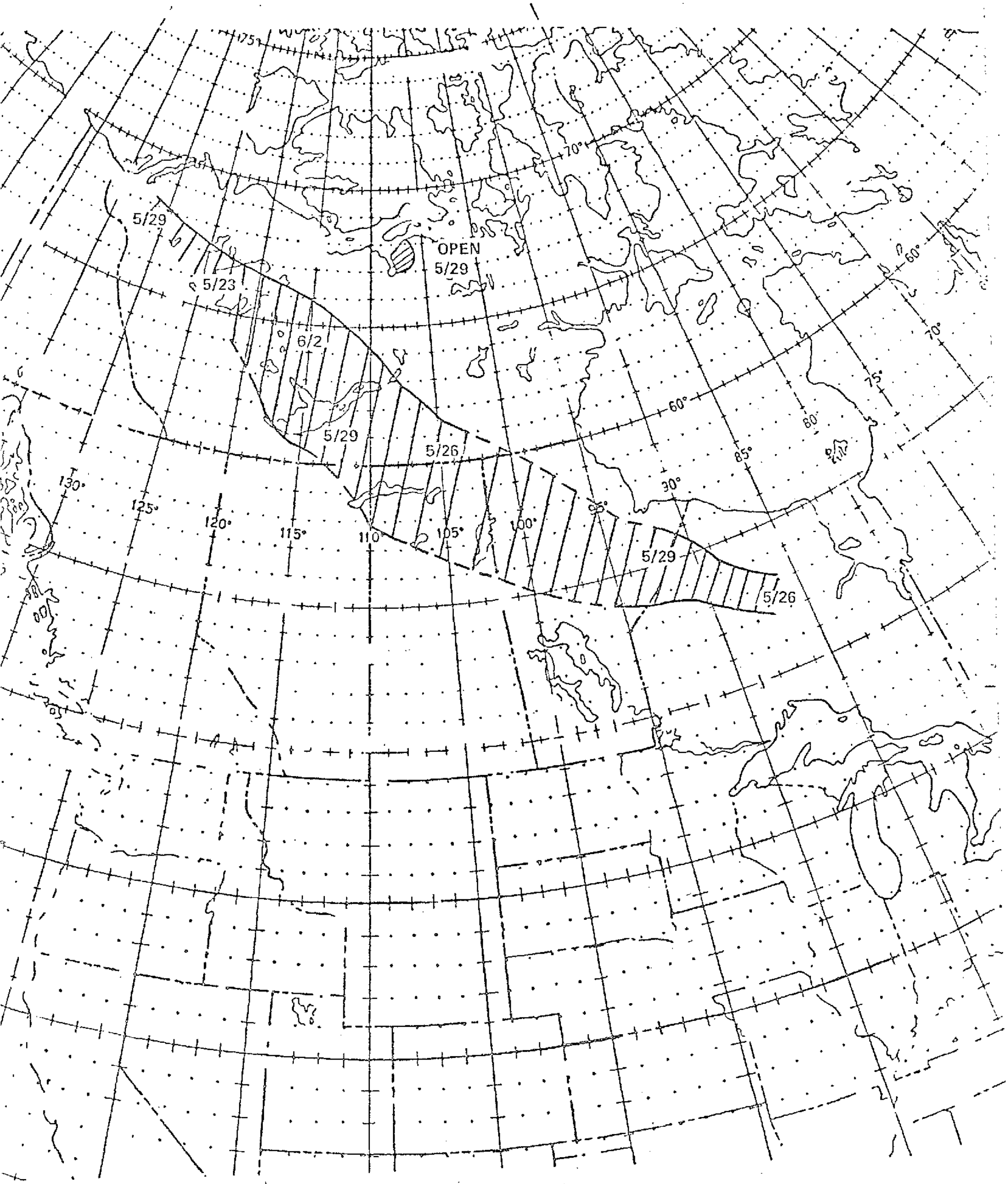


FIGURE 14. LAKE THAW TRANSITION ZONE FOR THE PERIOD MAY 26 THROUGH JUNE 2, 1973. DATES ON MAP INDICATE APPROXIMATE POSITIONS OF BOUNDARIES AT THOSE TIMES.

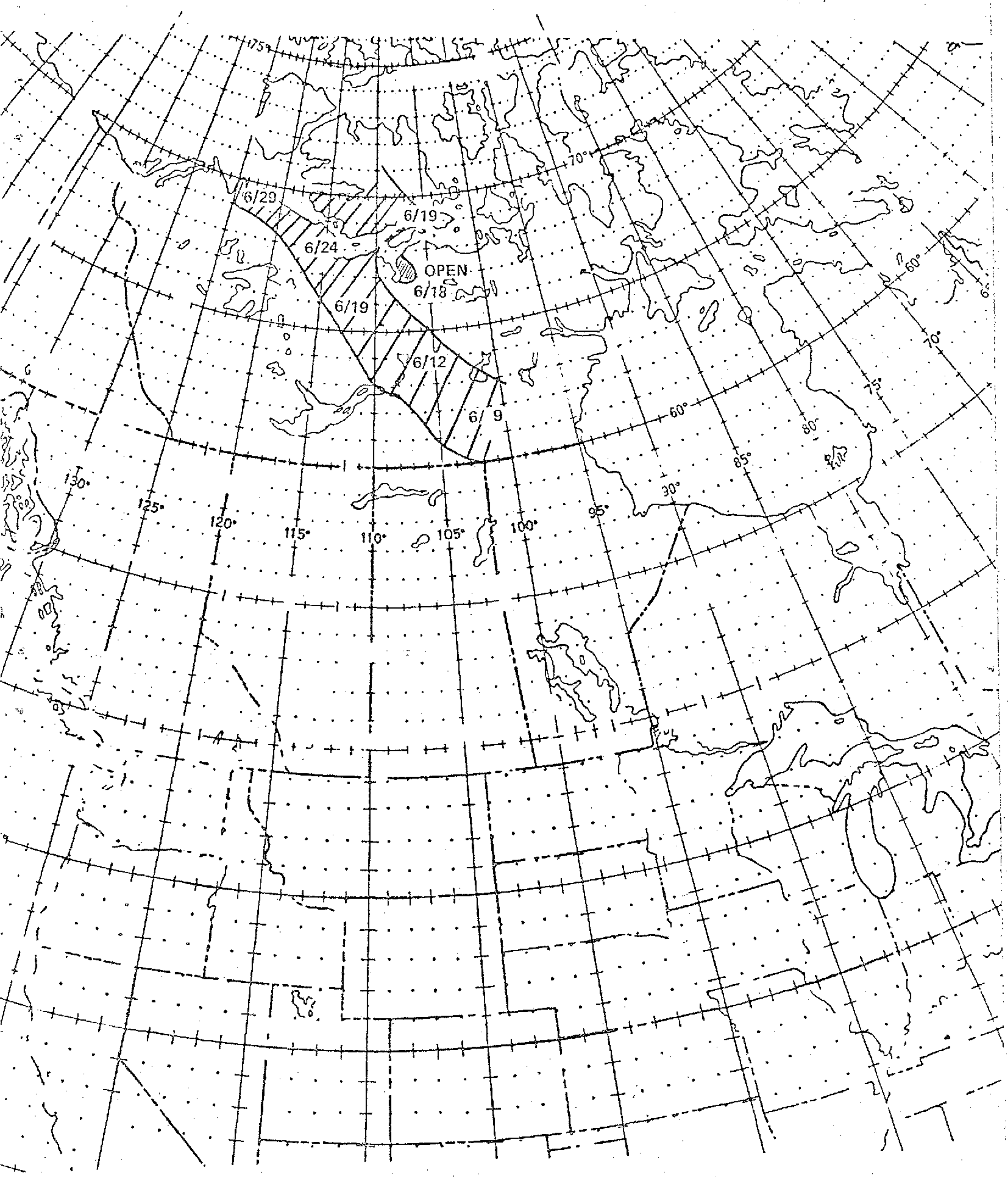


FIGURE 15. LAKE THAW TRANSITION ZONE FOR THE PERIOD JUNE 9 THROUGH JUNE 29, 1973. DATES ON MAP INDICATE APPROXIMATE POSITIONS OF BOUNDARIES AT THOSE TIMES.

3.2.2 Comparison With Earlier Studies

The 1973 thaw season and its accompanying transition zone were probably typical of other thaw seasons and zones. A comparison of the size, shape and location of transition zones observed by McFadden [8] in 1963 and 1964 agree remarkably well with the 1973 transition zone at similar points in time. In addition, lake "break-up lines," reported by Ferguson and Cork [9] from an analysis of weather satellite photographs taken over the years 1967 through 1970, closely resemble transition zone boundaries in geographic location and orientation at all times during the thaw season. Unlike the freeze season, the onset of the thaw season and transition zone migration appear to be consistent and systematic in both time and space. As a result, the possibility would seem to exist for predicting the movement of the thaw transition zone solely on the basis of time of year and locale. This matter will receive closer attention during the remainder of this investigation.

3.2.3 Comparison With Weather Systems

As has been previously reported in connection with this investigation [1], an intercomparison of the freeze transition zone and mesoscale weather systems revealed three features:

- Polar continental cyclones originate within and/or travel along the trend of the transition zone.

- Polar continental anticyclones fail to cross the transition zone.

- Polar outbreak anticyclones pass through the transition zone without undergoing any apparent change.

Because of these consistent trends during the 1972 freeze season, an attempt has been made to conduct a similar intercomparison for the 1973 thaw season.

Preliminary results indicate little correlation between the thaw transition zone and the movement of pressure centers. A sample comparison for late March 1973 is shown in Figure 16. On the basis of this sample, the transition zone appears quiescent relative to the movement of air masses. However, data from other time periods suggest the thaw transition zone is neither a hindrance nor an aid to the weather systems. This conclusion is only tentative; whether in fact an interrelationship exists must await a more detailed analysis.

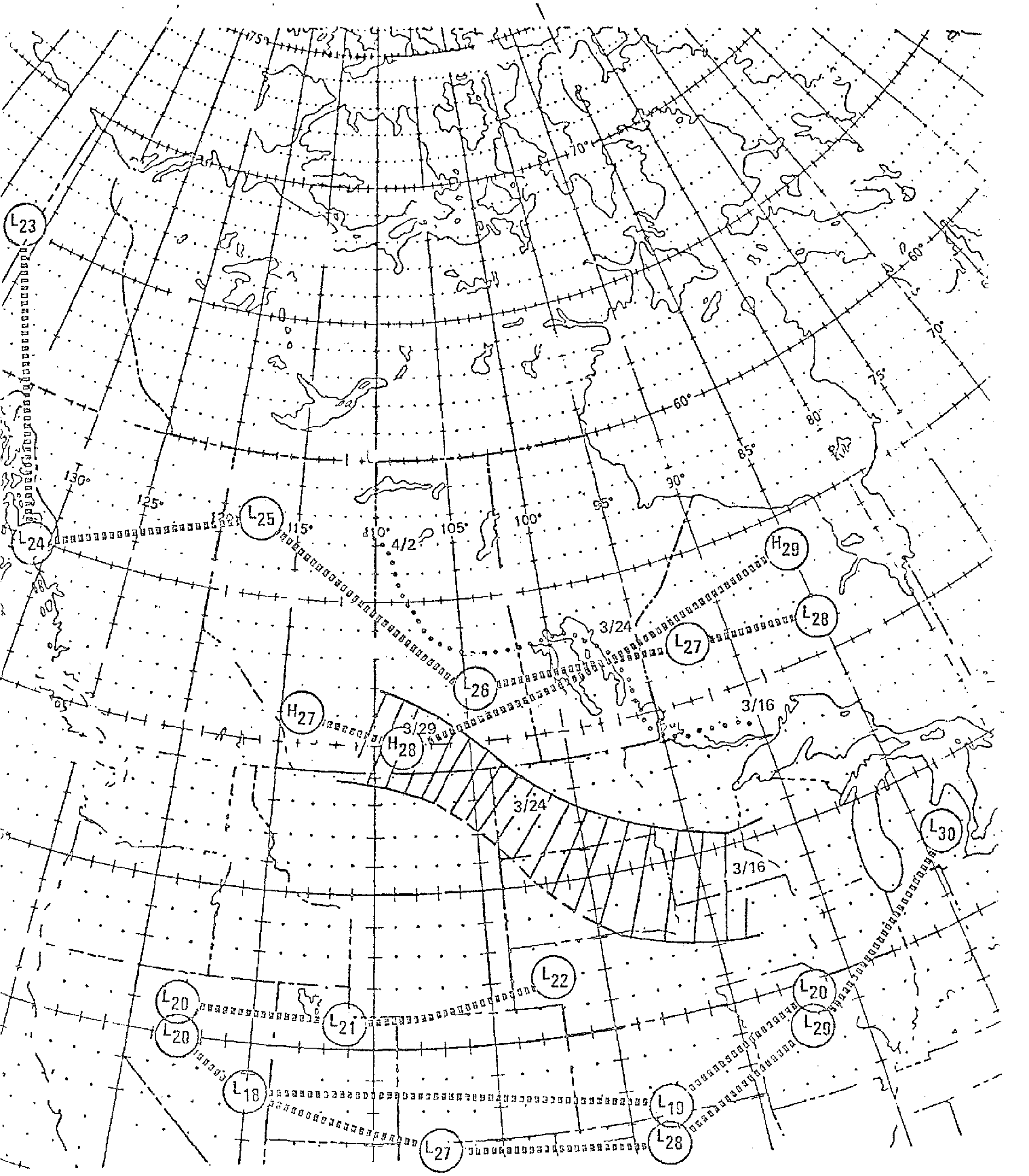


FIGURE 16. MOVEMENT OF AIR MASSES IN CENTRAL NORTH AMERICA BETWEEN 16 MAR 1973 AND 29 MAR 1973. (H = HIGH PRESSURE MASS; L = LOW PRESSURE MASS; SUBSCRIPT INDICATES DAY OF MONTH; TRANSITION ZONE GIVEN.)

SECTION 4.0
CONCLUSIONS

Despite the interim nature of many of the results reported herein, a few substantial conclusions may be drawn. First, to a fair approximation McFadden's criterion appears to hold for both the freeze and thaw seasons. That is, the deep lakes of a region generally will freeze (thaw) when the 40-day running mean air temperature reaches 0°C (4°C), and the shallow lakes will freeze (thaw) when the 3-day running mean air temperature reaches 0°C (4°C). As adopted here, the shallow lake RMT base period has been lengthened to 10 days. This modification has not appreciably affected the observational results, at least not on the scale of the weather station spacing. Consequently, whereas the exact freeze (thaw), date of a particular lake may be extremely difficult to predict, the relative position of the transition zone can be estimated quite well on the basis of RMT calculations. The predictive capacity of the RMT method would be limited solely by the confidence that would be placed in average daily temperature projections.

Secondly, the thaw transition zone appears to be remarkably consistent in its size, orientation, and geographical location from year to year. These consistencies may reflect the impact of incident solar radiation on melting processes, although radiation had been ruled out as the dominant mechanism for lake thawing in an earlier section of this report. Clearly, more work needs to be done to place the causal factors of lake ice melting and clearing, (1) solar radiation, (2) latent and sinsible heat, and (3) wind in their proper order of importance. Notwithstanding these physical difficulties, the empirical data suggest that it may be possible to draw thaw transition zone boundaries that remain fixed, within a reasonable confidence interval, from year to year.

In confirming McFadden's criterion, one of the major objectives of this investigation has been achieved. Concurrently, the possibility of making accurate predictions of transition zone movements based on that criterion or empirical observations appears greatly enhanced.

SECTION 5.0
RECOMMENDATIONS

In the few remaining months of this investigation, it is recommended that efforts be directed to verifying and substantiating the results of the previous year, in particular those reported here. Some of the obvious tasks have already been suggested; namely, (1) extend McFadden's RMT method to the 1973 thaw season, (2) test the validity of an empirical approach to determine transition zone boundaries, and (3) complete the analysis of transition zone correlations with weather systems and regional meteorological data.

SECTION 6.0
REFERENCES

1. Jelacic, A.J., The Interdependence of Lake Ice and Climate in Central North America, Interim Report for the Period June-November 1973, NASA Contract No. NAS 5-21761, 27 p., 1973.

2. Meteorological Observations in Canada, Monthly Record, Environmental Canada.

3. Jelacic, A.J., The Interdependence of Lake Ice and Climate in Central North America, Interim Report for the Period June-November 1972, NASA Contract No. NAS 5-21761, 31 p., 1972.

4. "Report on Significant Results and Projected Applications Obtained from ERTS 1: Volume 1, Results and Applications," NASA, Houston, Texas, May 1974.

5. Wolf Research and Development Corporation, Type I Contract Report No. 7, NASA Contract NAS 5-21761, 10 February 1974.

6. Wolf Research and Development Corporation, Type I Contract Report No. 8, NASA Contract No. NAS 5-21761, 10 April 1974.

7. McFadden, J.D., The Interrelationship of Lake Ice and Climate in Central Canada, ONR Contract Nonr 1202(07), Technical Report No. 20, 120 p., 1965.

8. Jelacic, A.J., The Interdependence of Lake Ice and Climate in Central North America, Interim Report for the Period December-May 1973, NASA Contract No. NAS 5-21761, 28 p., 1973.

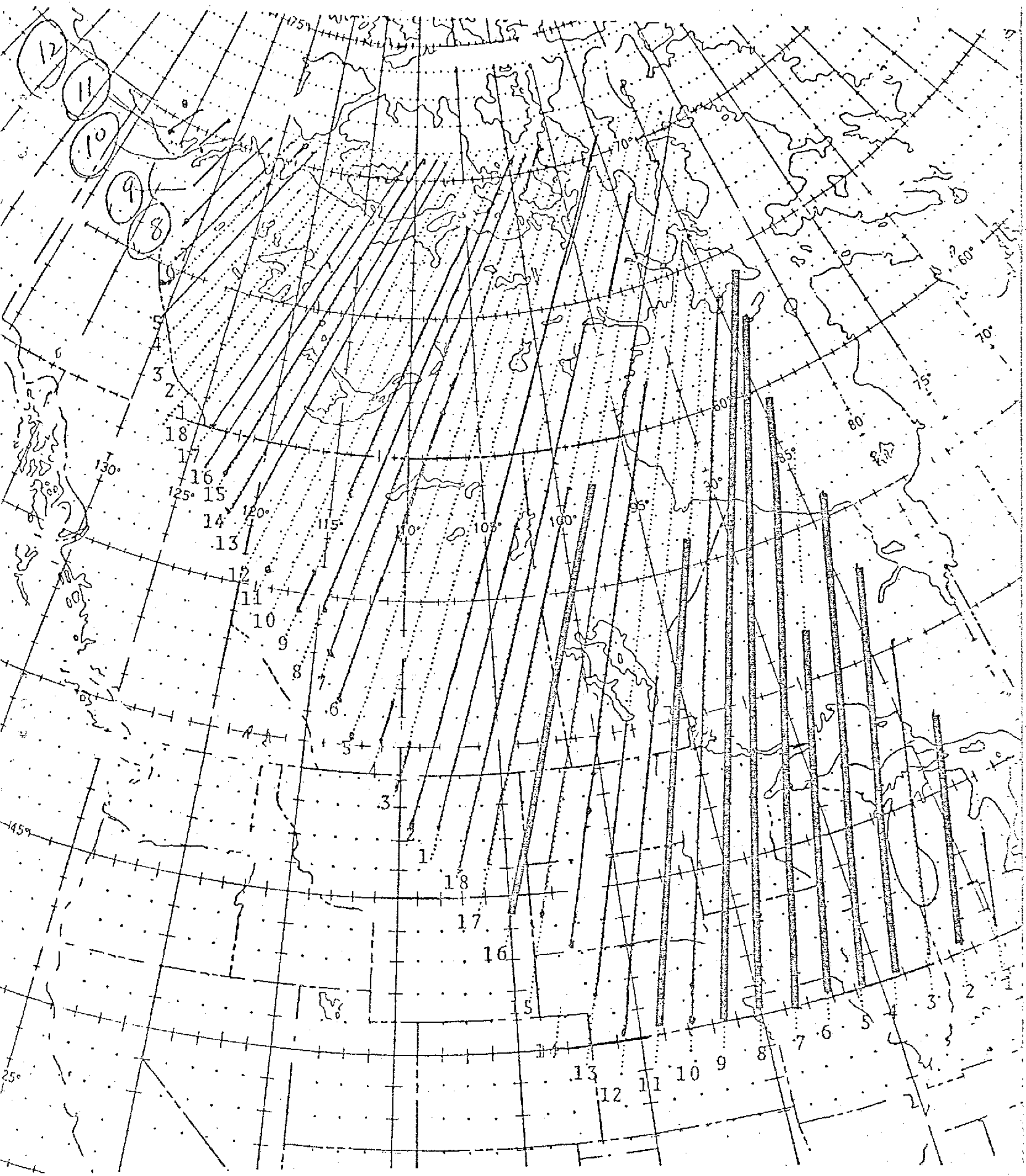
9. Ferguson, H.L. and H.F. Cork, "The Use of Satellite Photographs to Determine the Time of Freeze-Up and Break-Up of Canadian Lakes," Proc. First Canadian Remote Sensing Symp., Ottawa, 1972.

APPENDIX A

ERTS 1 SWATH COVERAGE*

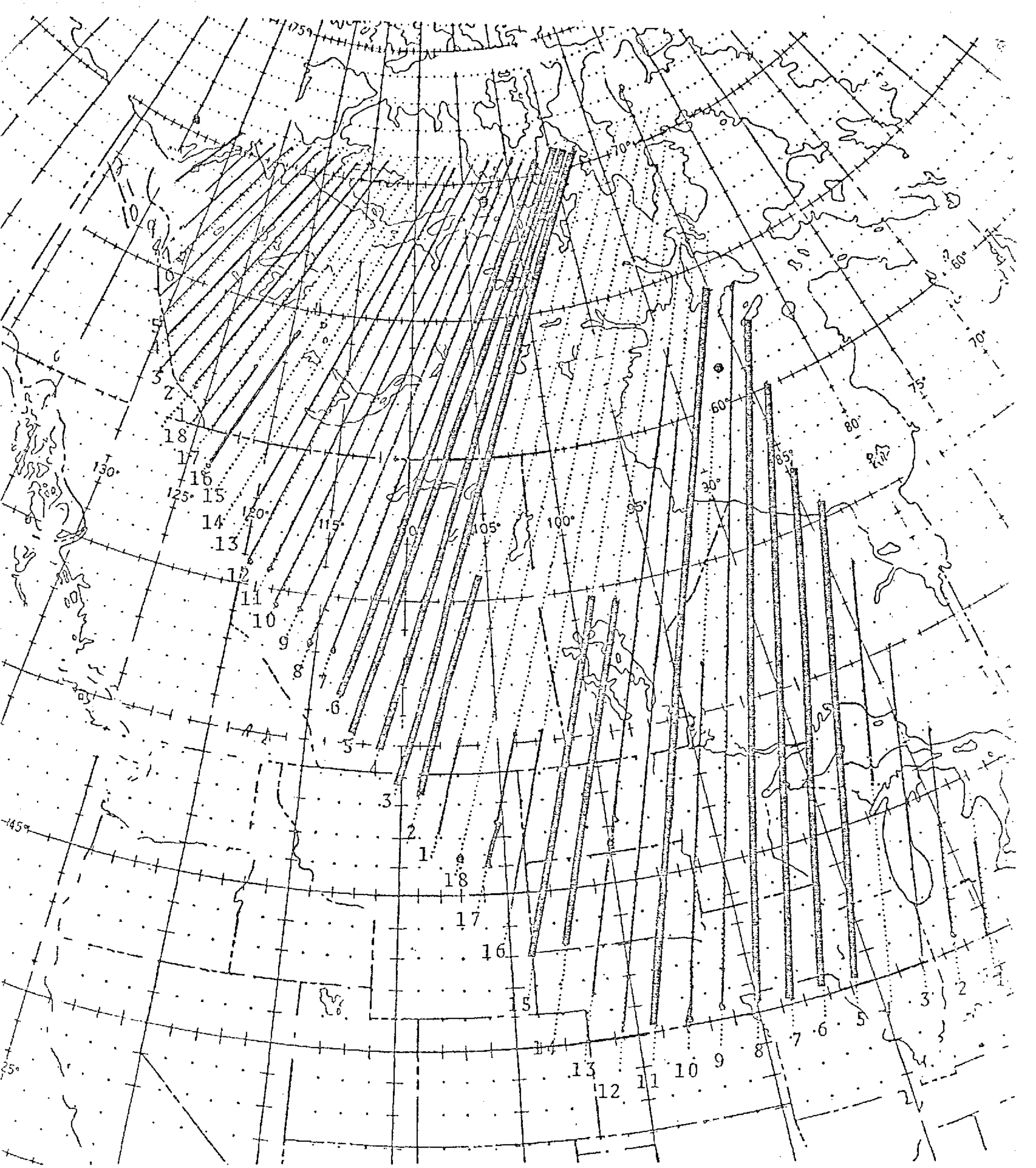
Spring 1973

*Solid lines represent imagery received for analysis; thick solid lines represent swaths in which the transition zone was observed.



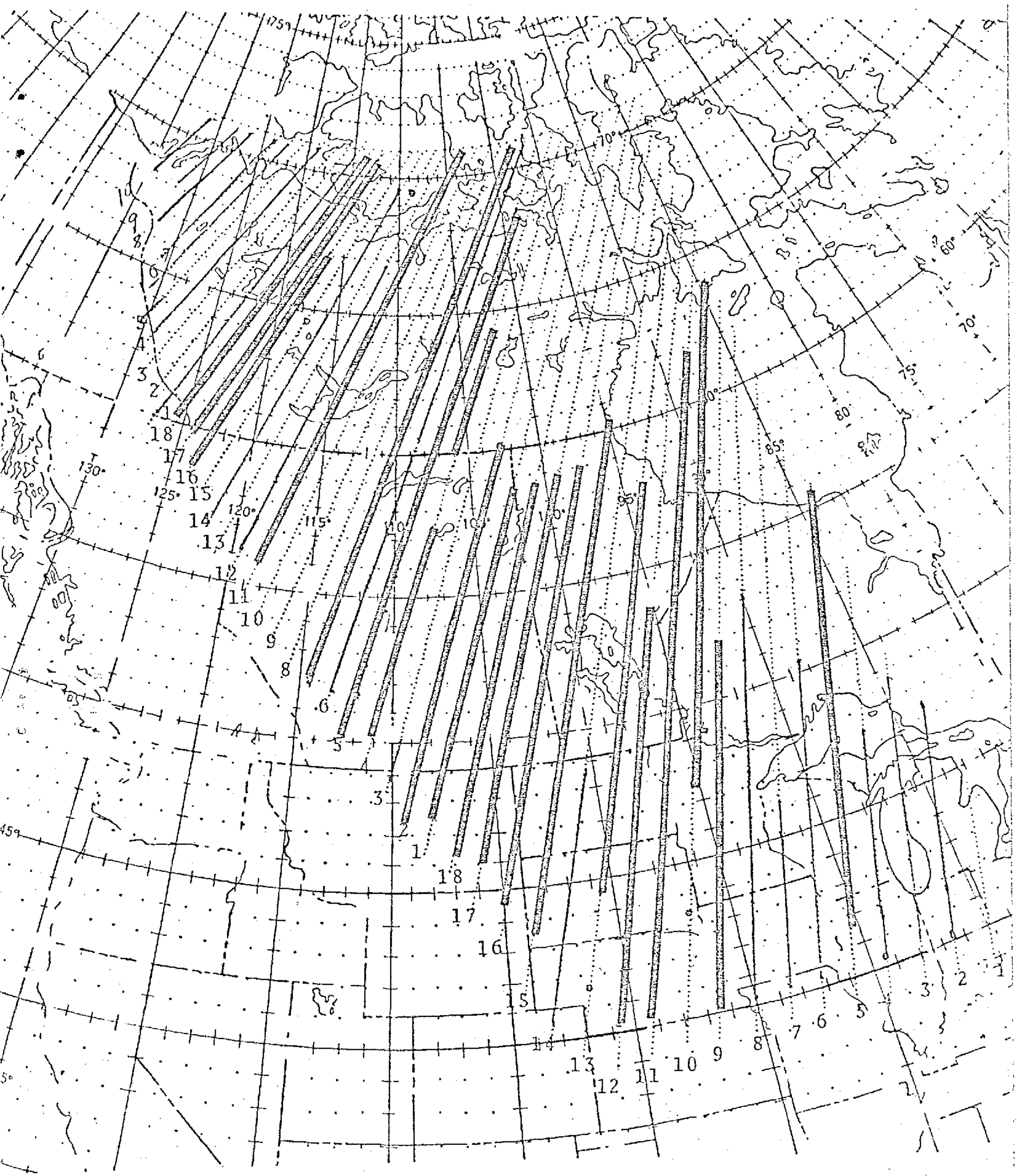
ERTS 1 GROUND TRACKS

CYCLE 13 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE MAR	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27



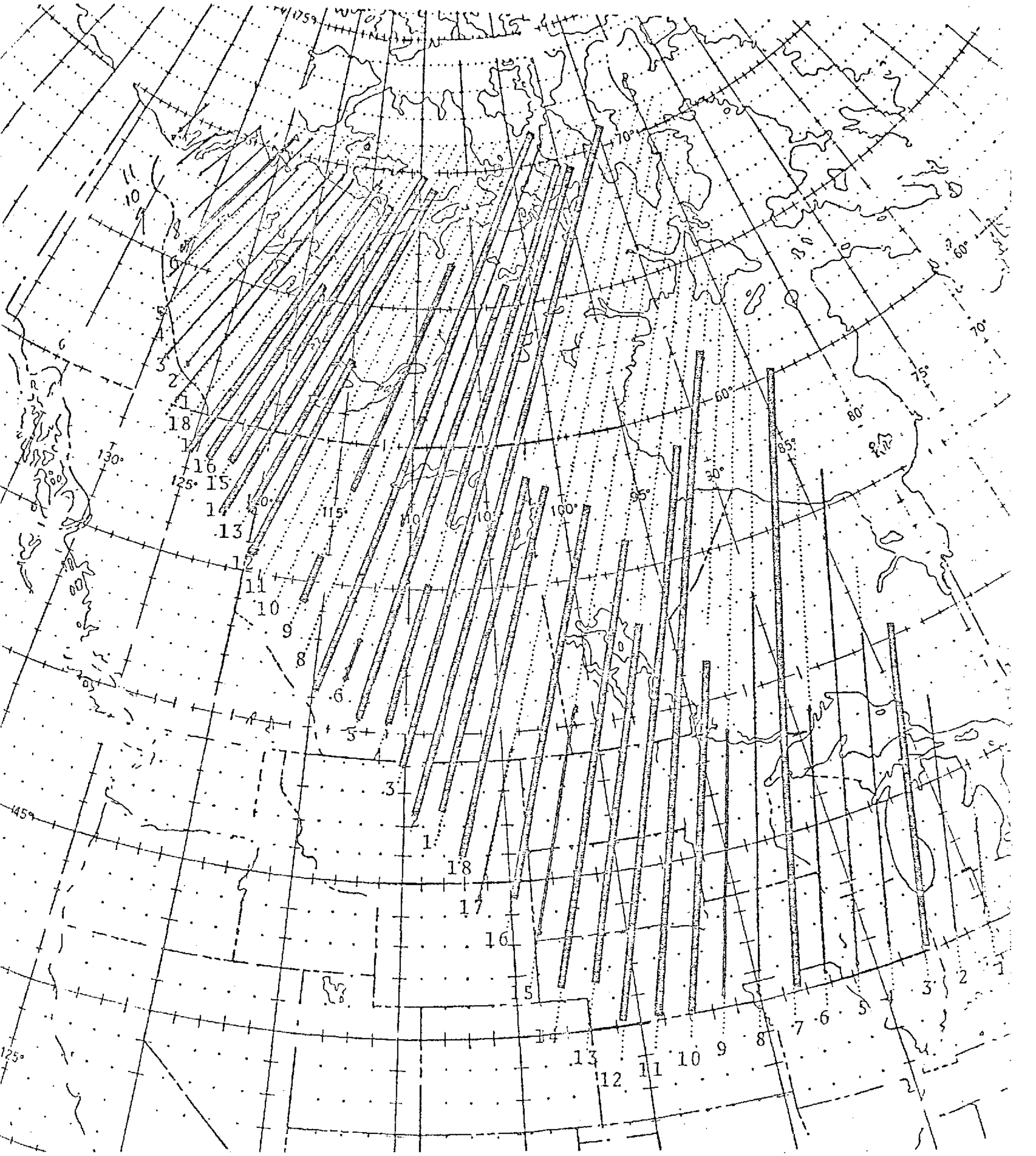
ERTS 1 GROUND TRACKS

CYCLE 14 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE MAR	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14



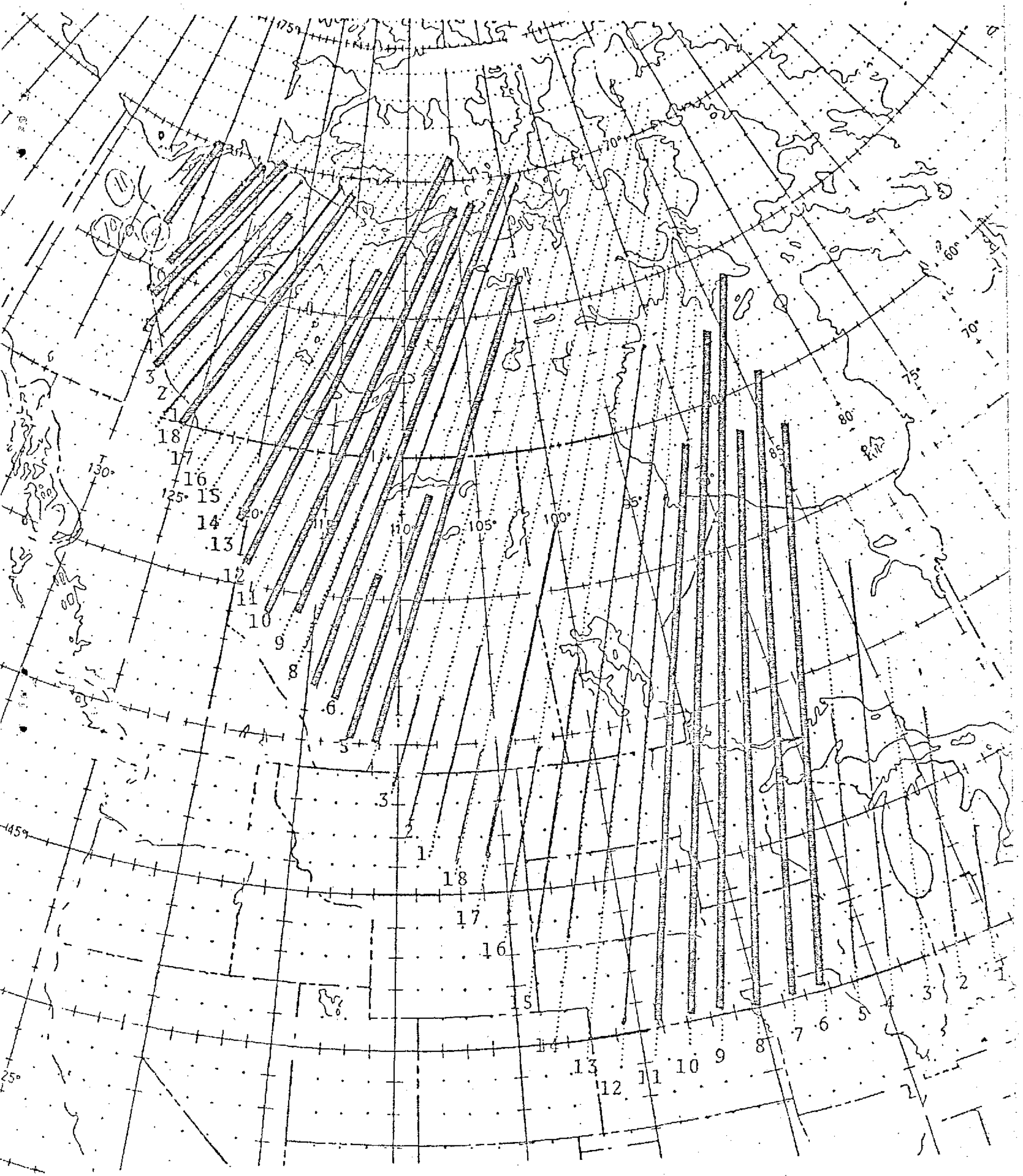
ERTS 1 GROUND TRACKS

CYCLE 15 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE APR	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2



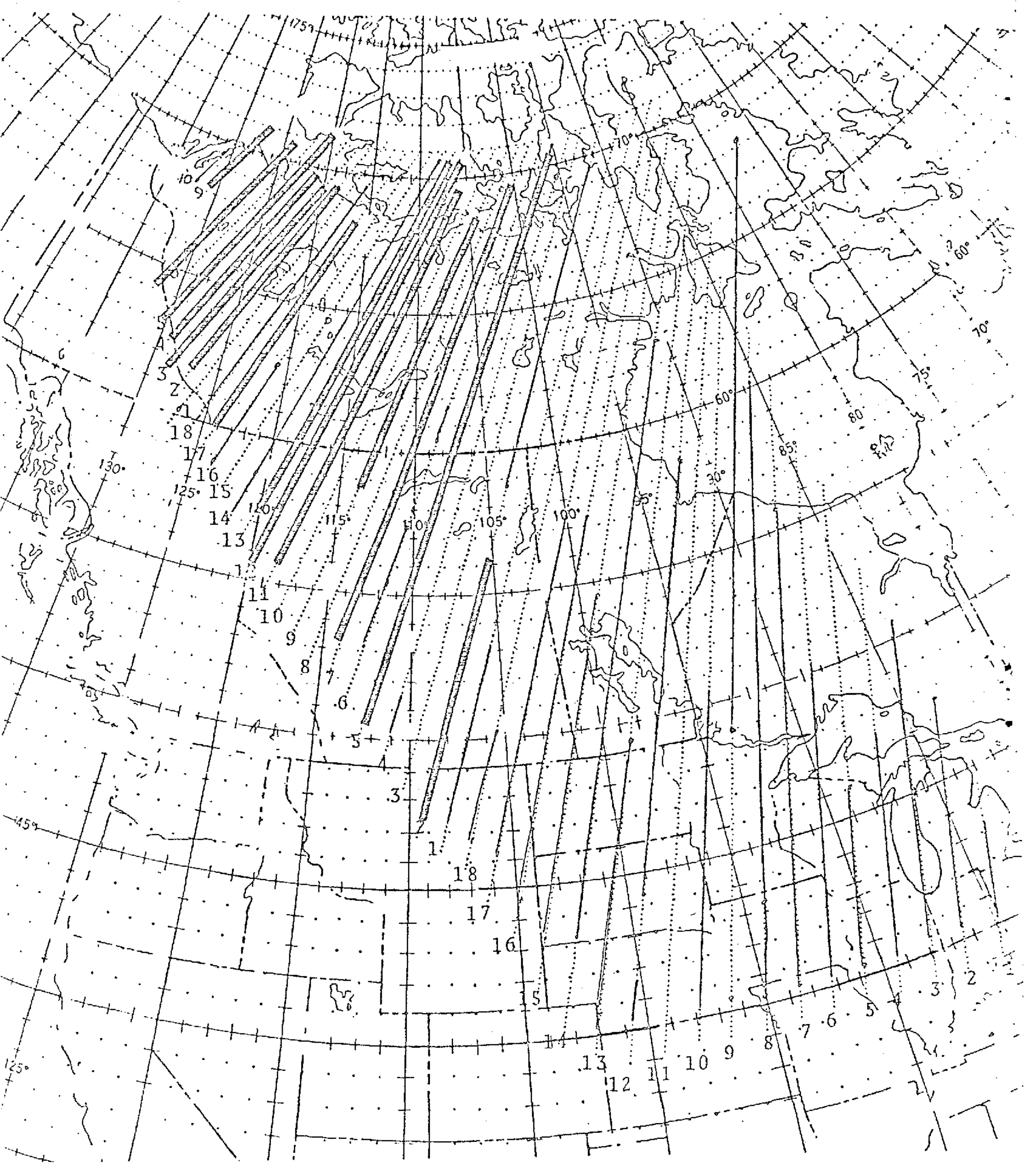
ERTS 1 GROUND TRACKS

CYCLE 16 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE MAY	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20



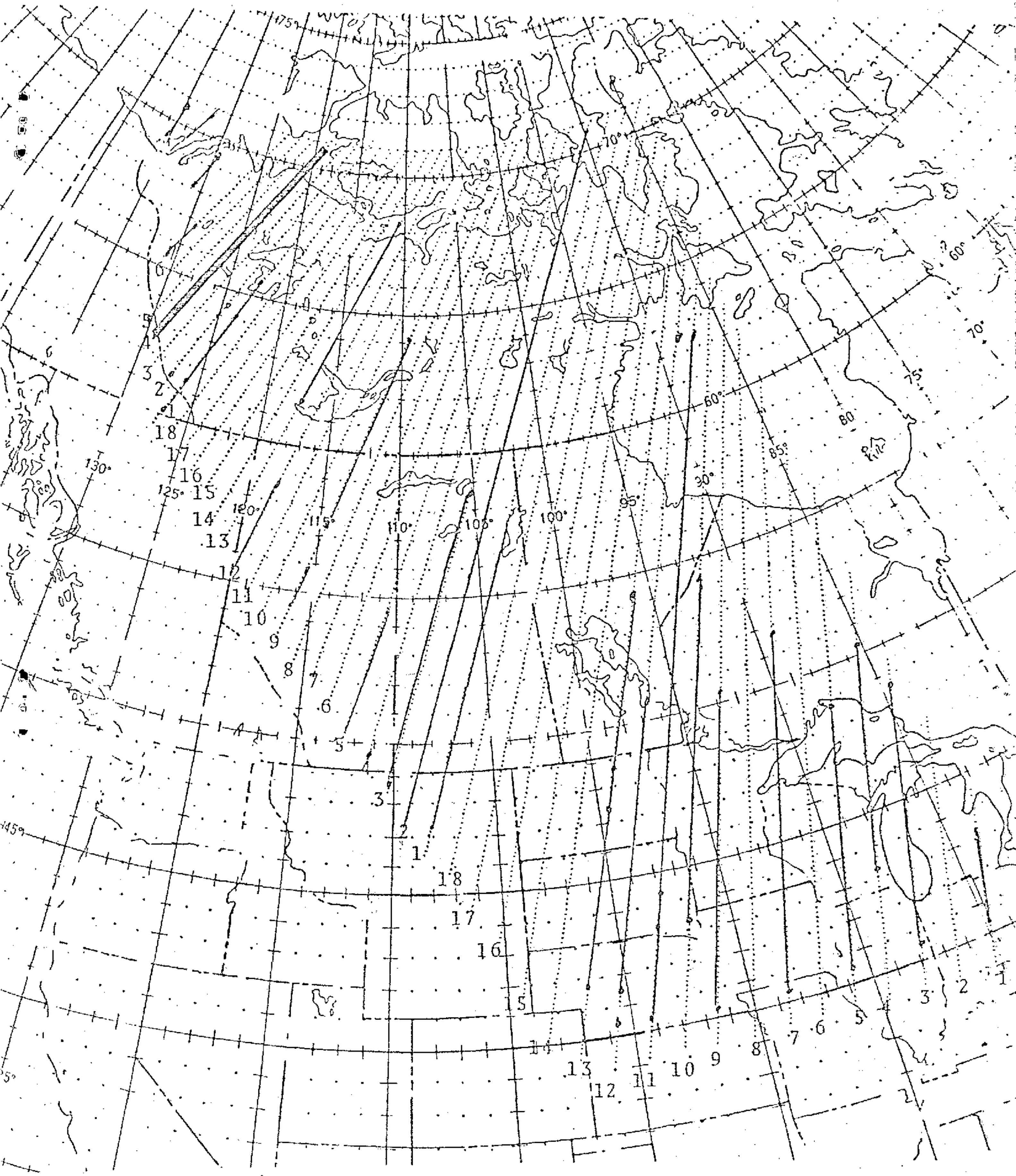
ERTS 1 GROUND TRACKS

CYCLE 17 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE MAY	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7



ERTS 1 GROUND TRACKS

CYCLE 18 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE JUNE	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25



ERTS 1 GROUND TRACKS

CYCLE 19 DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE JUNE	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13